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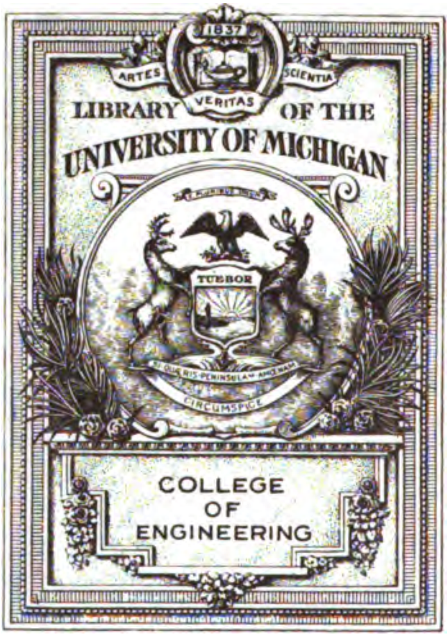

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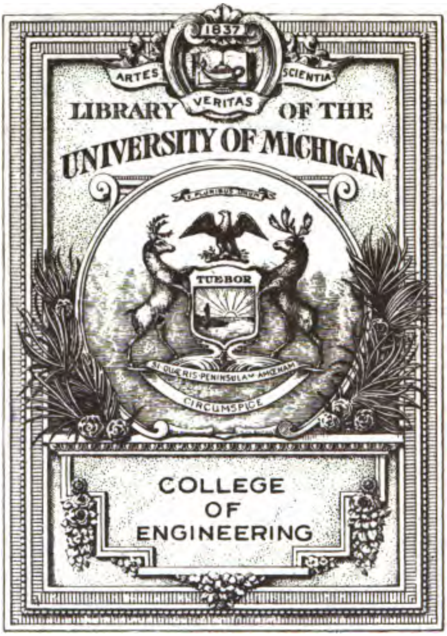
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Electrical Equipment

of the

Motor Car

A book on automobile electrical starting, lighting and ignition systems, for the lay reader, designed to give the motorist the knowledge necessary to enable him to care for and repair any and all of the electrical features of his car, no matter what make or model it may be. Equally valuable to the repair man whether he be skilled in things electrical or have a very limited acquaintance with them.

BY

David Penn Moreton
and Darwin S. Hatch

NEW YORK
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1918

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PREFACE

Electrical apparatus enters so deeply into the design and operation of the modern motor car that it is impossible to operate or repair intelligently any motor vehicle without some knowledge of how electricity has been applied to the car and without a fair idea of how such electrical phenomena as we find in the car are produced.

It is unfortunate that so important a feature of the modern car has been regarded so long as something mysterious and one which none except an expert may thoroughly understand. Much of this atmosphere of mystery has been thrown about the electrical apparatus of the car by the lack of really thorough printed matter on the subject. The majority of the books which treat of electricity as applied to the car have assumed considerable knowledge of elementary electricity on the part of the reader, and hence have rather befogged the issue in the minds of any who attempt to study them without some previous knowledge of the subject.

It was with the idea of treating the entire electrical apparatus in its relation to the car from the standpoint of one who knew absolutely nothing of electricity that a series of articles was prepared and published in "Motor Age." This series was reprinted in this book with such additions and changes as inquiries and suggestions from readers of "Motor Age" had made it seem advisable.

The present volume is designed to give the owner and repairman, whether or not he be an electrical expert, that knowledge of the fundamentals of electricity and its application to cars in general that will permit him to properly operate, care for electrical equipment of any car and repair any electrical trouble in any car.

It is urged that in using this volume the reader be certain that he understand the fundamentals of electricity as outlined

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in the earlier chapters before he attempts to understand the practical applications of electricity as outlined in later chapters.

A later, volume which will incorporate the matter now running serially in ''Motor Age'' will be concerned wholly with the electrical equipment of individual cars, taking up all of the more common cars with explanations of their equipment and of the care of each particular installation.

The two volumes will be independent, but the later one presupposes a thorough understanding of the matter covered in this first volume.

In this the effort has been to tie the new ideas of electricity up with the more common things of everyday life with which the readers are familiar. For this reason such analogies as the analogy of the flow of electricity to the flow of water, and similar comparisons have been carried throughout the work.

DAVID PENN MORETON
DARWIN P. HATCH

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ELECTRICAL EQUIPMENT OF THE MOTOR CAR

CHAPTER I

Fundamentals of Electrical Circuits

ELECTRICITY in its many applications, as found on the modern motor car, plays no small part in the successful and satisfactory operation of the motor car as a unit and the degree of comfort and luxury it is possible for the manufacturer to provide.

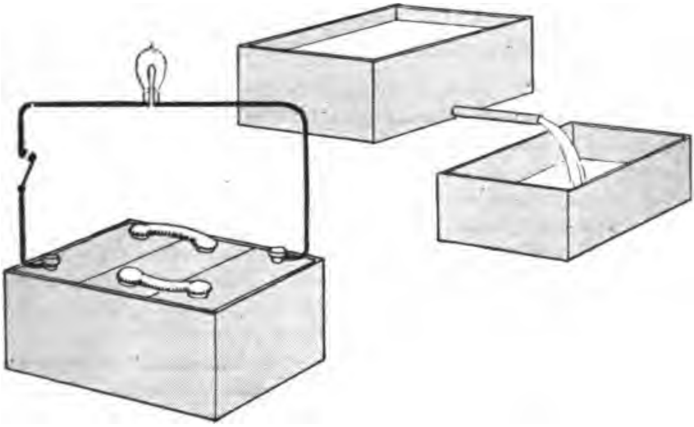
It is responsible for the spark that ignites the mixture of gas and air in the cylinder and makes the engine operate; it lights the car, starts the engine, and operates the horn. There are cars in which it heats the fuel; others in which it shifts the gears and in some still newer designs, even replaces clutch and gearset in the transmission of the power of the engine to the rear wheels.

The exact nature of electricity is not known and no attempt will be made to give any explanation as to what it may be. You can, for convenience, think of electricity as being the name given to that something which produces certain results which we call electrical, such as lighting, the arc formed when a trolley wheel breaks contact with the trolley wire, the sparks formed in stroking the cat's back, etc. We are all familiar with the fact that if we step out of a window without any means of support, we are sure to fall to the ground or sidewalk. The reason of our falling is due to the attraction of the earth on our bodies, which is called gravity. The exact nature of this attraction is not known any more than the exact nature of electricity is known. The action of gravity under certain definite conditions, however, is well known, and so is the action of electricity under certain definite conditions quite well known.

Since we know the action of electricity under definite conditions, it is possible to make practical use of it in operating the lamps, starting, motor, etc., on the motor car, even though its exact nature is not known. For the sake of convenience in dealing with electricity, we can think of it as a fluid such as water, but it must be remembered at all times that this similarity has to do with the action only and does not necessarily mean that the two are identical.

The Electrical Circuit

The electrical circuit is the fundamental basis of the many applications of electricity to the motor car, and, in order to understand thoroughly the principles, operation and maintenance of these applications, it is essential that we have a quite complete knowledge of the electrical circuit and its more common properties and characteristics.



Figs. 1 and 2—Electrical and water circuits contrasted. The electrical circuit at the left must be complete before there will be a current of electricity, but the water system, at right, need not be a complete circuit for a current of water to flow in it

The electrical circuit is the path in which the electricity flows, just as the water pipe is the path in which the water flows or a river bed is the path in which a river flows.

There is one great difference, however, between the electrical circuit and the ordinary circuit in which the water flows, and that is that the electrical circuit is always closed on itself while the water circuit is not necessarily always closed.

This difference may be illustrated by two different examples as follows: Suppose we take a small lamp and connect it to a storage battery by means of wires and a switch, as shown in Fig. 1. There will be no flow of electricity through the lamp unless the switch is closed, or, as we say in practice, unless the circuit is complete. In the case of the flow of water in a pipe, the pipe may be conducting the water from one tank to another as shown in Fig. 2 and it is not necessary to have a pipe from the second or lower tank back to the first or higher tank in order that there be a flow of water in the pipe.

The fact that *the electrical circuit must be complete and cannot merely conduct electricity from one point to the other, as the pipe conducts water from one tank to the other*, Fig. 2, is the keynote of the electrical circuit. Referring to Fig. 1—the complete electrical circuit is made up of many parts, wires, lamps, switch, battery terminals, battery plates, electrolite, etc., all combined in a continuous path, circle or circuit, as you choose to call it.

We can think of the electrical circuit just as we think of the circle; that is, it is continuous and has neither beginning nor end. If we started at any point on the electrical circuit and follow along the circuit we will arrive at the point from which we started just as we return to the starting point in following along a circle, regardless of the point from which we started.

In order to emphasize the importance of the reader getting this circuit or circle idea thoroughly in mind, the various circuits of the modern motor car are indicated in their circular form in Fig. 3. These circuits and their relations to each other will be taken up in detail later. It is not humanly possible to make changes or locate troubles in the electrical equipment of a car unless this circuit idea is followed, either consciously or unconsciously.

The circle or circuit is to electricity what the metal rails are to the railroad train. Your train cannot run without the track, as electricity cannot be made use of except in a circuit.

Let us draw a circuit parallel from nature: If we follow a drop of water along one of Nature's circuits, as shown in Fig. 4, the water falls as rain upon the ground, runs into the little brooks, creeks, larger rivers and then into the ocean, where it is in turn evaporated by the sun, then carried over the land in the form of

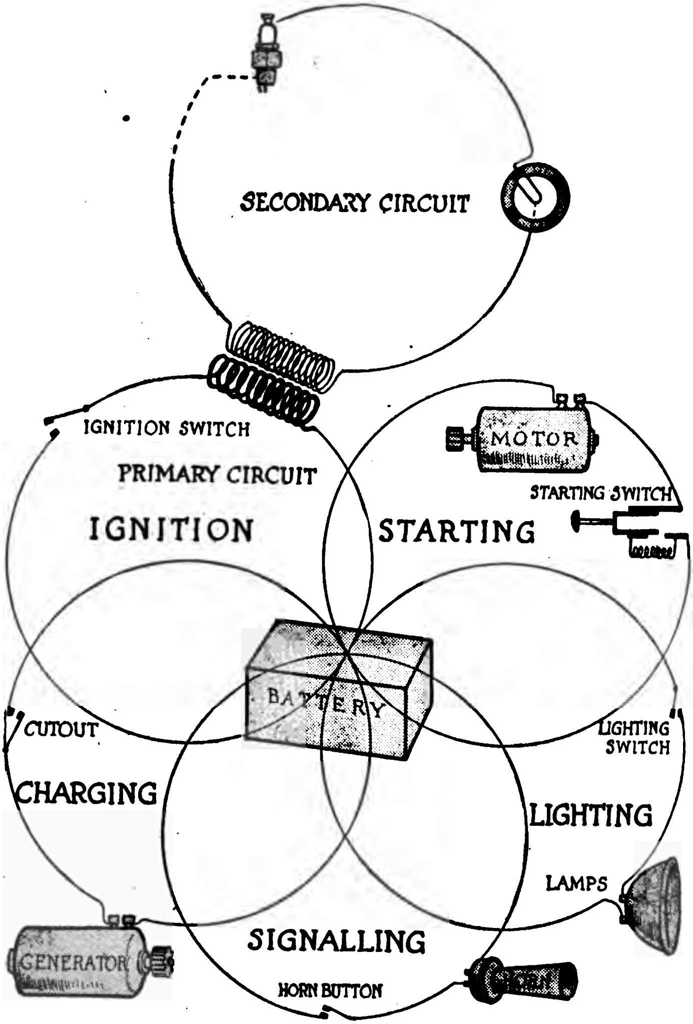


Fig. 3—The major circuits in the motor car. Starting, lighting, ignition, signalling and all electrical features of the car are operated in complete circuits which are indicated here as circles

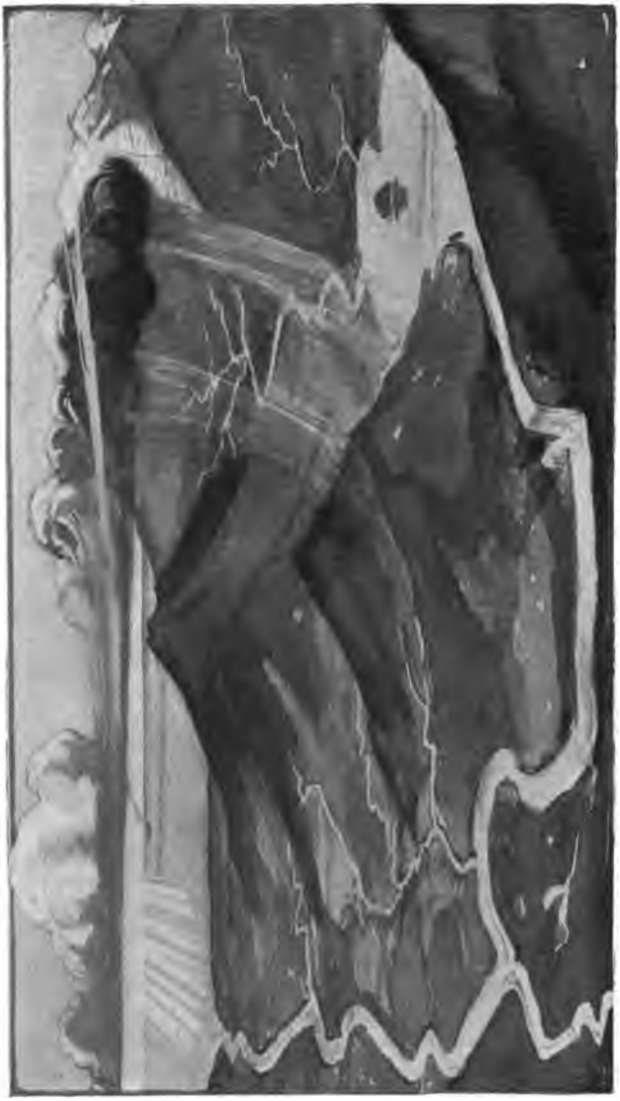
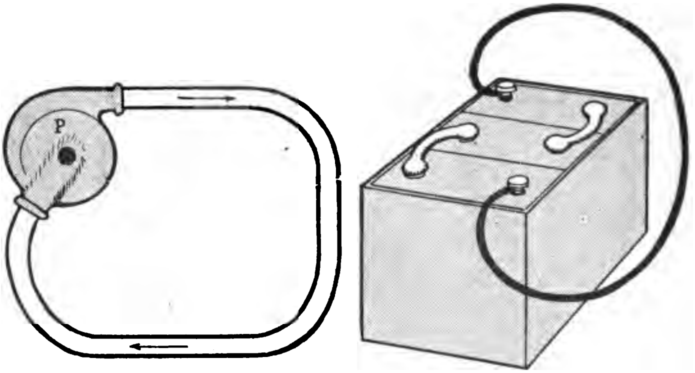


Fig. 4—Nature's great water circuit, typical of the electric circuit. A drop of water falls as rain upon the ground, runs finally into a river and thence into the ocean, where it is evaporated by the sun and carried back in the form of clouds over the land and again falls as rain to repeat its travels again and again

clouds by the wind, and again falls as rain. The path of the water in this great natural circuit—which we will call Nature's circuit—corresponds in a great measure to the electrical circuit inasmuch as it is a circle, a system without start or finish, beginning or end.

It is evident that in Nature's water circuit there may be an accumulation or decrease in the quantity of water at any point in the circuit. That is, the amount of water evaporated by the sun in a given time is not necessarily equal to the quantity falling as rain in the same time. Nor is the amount flowing into the ocean from the rivers in a given time necessarily equal to the amount running into the rivers from their various tributaries and along their banks in the same time.



Figs. 5 and 6—Simple water and electrical circuits. The battery may be likened to the pump and the wire to the water pipe. Both of these circuits are complete

In an electrical circuit similar to Fig. 1, the quantity of electricity leaving the lamp is exactly equal to the quantity of electricity entering the lamp and the same quantity of electricity returns to the battery as leaves it. There is no accumulation of electricity at any point along the electrical circuit similar to the accumulation of water at different points along Nature's water circuit.

The operation of a water circuit similar to the one shown in Fig. 5 corresponds more nearly to the operation of the simple electrical circuit than Nature's water circuit. The water circuit shown in Figure 5 consists of a pump P connected to a curved piece of pipe.

When the pipe and pump are filled with water the flow of the water in the pipe, due to the action of the pump, will be very similar to the flow of the electricity in the simple electrical circuit shown in Fig. 6, whch consists of a piece of wire connected to the terminal of a storage battery. Both of these circuits are complete; they are closed on themselves and, like the circumference of a circle, have neither beginning nor end.

The quantity of water entering one end of the pipe from the pump is exactly equal to the quantity of water leaving the other end of the pipe and entering the pump. Likewise the quantity of electricity entering one end of the wire from the battery is exactly equal to the quantity of electricity leaving the other end of the wire and entering the battery. The pump does not produce the water but merely causes the water to flow through the pipe. The battery does not create electricity, but merely causes the electricity to flow through the wire.

Electrical Current

It is obvious that the action of the pump in the water circuit and the action of the battery in the electrical circuit are very similar. There is a mechanical pressure produced by the pump which causes the water to flow through the pipe, and the battery produces what is called an electrical pressure which causes the electricity to flow through the wire.

If the mechanical pressure produced by the pump be increased or decreased, there will be a change in the flow of the water in the pipe, the flow increasing with an increase in pressure and decreasing with a decrease in pressure. This flow, or movement of the water in the pipe, may be measured by determining the number of gallons passing a certain point in the pipe in, say, 1 second. You could then speak of the flow of water in the pipe as being so many gallons per second. Any unit of quantity and time may be used in expressing the flow of water in a pipe, such as so many cubic feet per minute, so many gallons per hour, etc.

The flow or movement of electricity in the electrical circuit is measured in a similar manner to the flow of water in a pipe; that is, by determining the quantity of electricity passing a certain point in the electrical circuit in a certain time. Instead of measuring the quantity of electricity in gallons or cubic feet, as in the measurement of water, it is measured in a unit called the coulomb.

In referring to a certain quantity of electricity it is spoken of as so many coulombs just as a certain quantity of water is spoken of as so many gallons, so many cubic feet, etc.

The Ampere

If the water in a pipe, such as the one shown in Fig. 5, is moving at such a rate that there is 1 gallon of water passing every point along the pipe each second, there is said to be a flow of 1 gallon per second in the pipe. Similarly, if the electricity in a circuit, such as the one in Fig. 6, is moving at such a rate that there is 1 coulomb passing every point in the circuit in each second of time, there is said to be a flow of 1 coulomb per second. The flow, or movement of the water in the pipe, is called the current of water, just as the flow of the water in a river is called the current, and, likewise, the flow of the electricity in the electrical circuit is called the current of electricity or more commonly the electrical current. From the above discussion, it is seen that the current of water is expressed as so many gallons per second, so many cubic feet per minute, etc., while the current of electricity is expressed as so many coulombs per second.

Fortunately we have a special name for this rate of flow of electricity of one coulomb per second, which is called the ampere. This way of giving the rate of flow a special name relieves us of the necessity of saying ''per second'' each time, as would be the case if we were to speak of the current as so many coulombs per second. Thus a current or rate of flow of 10 coulombs per second is just 10 amperes; 50 coulombs per second is 50 amperes, etc. In the majority of cases we are not interested in the quantity of electricity alone, but in the rate of flow, the ampere, and for this reason the coulomb is very little used.

Unfortunately there is no name for the rate of flow of water, and we always have to use some such cumbersome expression as gallons per second, cubic feet per minute, etc.

The number of gallons per second of water flowing through a pipe depends in a large measure upon the pressure causing it to flow. This pressure in the water circuit is measured as so many pounds per square inch or so many pounds per square foot. In a similar manner, the current of electricity, in amperes, in a wire depends in part upon the pressure under which the electricity flows.

The electrical pressure is measured in a unit called the volt. The volt means exactly the same thing in speaking of an electrical circuit as the pound pressure does in speaking of the water circuit. A higher pressure will be required to force the same current of water through a small than through a large pipe, and a higher electrical pressure will be required to force the same current of electricity through a small wire than through a large one. Similarly higher pressures will be required in both the water and electrical circuits if the length of the circuits be increased; that is, if the length of the pipe and wire be increased.

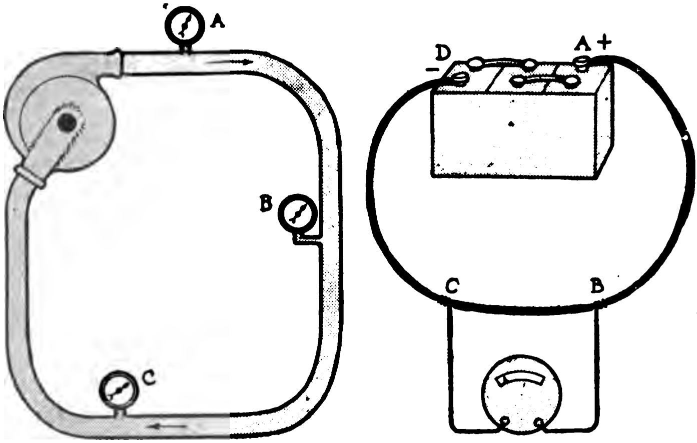
Electricity Moving Force

The pressure produced by the pump might be called the water moving force, while the pressure produced by the battery may be called the electricity moving force or electromotive force. The electromotive force is usually represented by the abbreviation e.m.f.

If pressure gauges be connected at various points along the water pipe, Fig. 7, they will indicate the pressure at the different points. There will be a difference in the pressure as indicated by the various gauges, if there is a current in the pipe, and their indications will be less and less as you pass along the pipe in the direction in which the water is flowing. The difference in the value of the pressure as indicated by any two of the gauges connected to the pipe will represent the pressure acting on the portion of the pipe between the two points where the gauges are attached. This difference in pressure between two points on a pipe is called the drop in pressure or merely the drop between the two points. The pressure between two points along a stream of water is often spoken of as the difference in level, the drop in level or merely the drop between two points.

In the case of the electrical circuit, there is a difference in the electrical pressure between two different points along the circuit. This difference in pressure between any two points is measured in volts just as the total pressure produced by the battery is measured in volts. The pressure at any point in an electrical circuit cannot be measured by attaching a suitable instrument to the circuit at that point alone, similar to the attachment of the pressure gauge to the water pipe, but the instrument must be attached to two points as shown in Fig. 8, and then it does not read the pressure at any particular point but the difference in the pressure between the two points on the circuit where it is connected. This difference in pressure, or voltage, as it is usually called, between any two points along a circuit is sometimes spoken of as the drop between the two points.

The water in the pipe flows from a point of higher pressure toward a point of lower pressure. The electricity in the electrical circuit flows from the point of higher electrical pressure or higher electrical level toward the point of lower electrical pressure or electrical level. In the electrical circuit the point of higher pressure is usually marked with the plus sign (+) and the one of lower pressure with the minus sign (—). The terminal of the battery from which the electricity flows when the battery is discharging, is called the positive terminal, while the terminal toward which the electricity flows is called the negative terminal.



Figs 7 and 8—The pressure in an electrical circuit, at the right, changes along the wire just as the pressure in the water circuit, at the left, decreases along the pipe—How the difference in pressure is measured

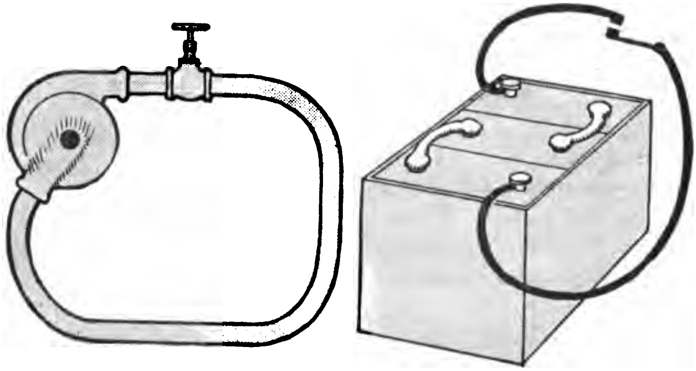
Any point along the wire will be positive with respect to points further along the wire in the direction of the current, and negative with respect to points along the wire opposite the direction of the current, just as the pressure indicated by any gauge is higher than the pressure indicated by gauges connected to the pipe at points further along the pipe in the direction of the water current and lower than the pressure indicated by gauges connected to points on the pipe opposite the direction of the water current.

To explain: In Fig. 8 point A is at a higher electrical pressure than B, likewise B is at a higher electrical pressure than C, so that B is positive with relation to C, but negative with relation to A.

The reader should have clearly in mind by this time the distinction between amperes and volts. The amperes represent the value of the current in the circuit—that is, the number of coulombs of electricity that pass through the circuit during one second, while the volts represent the pressure causing this current or movement of electricity.

Resistance to the Flow of Electricity

It is possible in both the water and electrical circuit to have a pressure acting in the circuit when there is no current. It is perfectly plain that if the path of the water be blocked or interrupted by closing a valve in the pipe, Fig. 9, there will be no current of water, although there may be a high pressure produced by the pump. If the path in which the electricity moves is blocked or interrupted by opening a switch or cutting the wire, there will be no current in the circuit, although the pressure may be high.



Figs 9 *and* 10—*The effect of resistance. In a water circuit, if the valve is closed, there will be no flow of water, though there may be a high pressure at the pump; in the electrical circuit if the wire is cut or switch is opened there is no current, though the battery may have a high electrical pressure*

The currents of water and electricity are, therefore, dependent upon something besides the pressure. This something which opposes the flow of water in the water circuit and the electricity in the electrical circuit is called the resistance of the circuit. The resistance of an electrical circuit simply opposes the free flow of eletricity through the circuit; yet the resistance does in no way tend to cause the electricity to flow in the direction opposite to that in which it is flowing. If you push against the wall of a building, the wall opposes the action of your force, yet the wall will not push you backwards when you stop shoving.

The greater the resistance of an electrical circuit the less the current a certain pressure will produce and the smaller the resistance of the circuit the greater the current a certain pressure will produce.

There is no unit in which the resistance offered by a pipe may be measured. The resistance of an electrical circuit is measured in a unit called the ohm. A circuit is said to have a resistance of 1 ohm where an electrical pressure of 1 volt will produce a current in the circuit of 1 ampere.

Electrical and Water Circuits

The following table gives in condensed form the names of the units in which the common qualities associated with the electrical and water circuits are measured:

	Water	Electricity
Quantity	Gallon, cubic foot, etc.	Coulomb
Current	One gallon per minute, one cubic foot per minute, etc.	Ampere One coulomb per second
Pressure	Pounds per square inch or pounds per square foot	Volt
Resistance	No unit	Ohm

Pressure the Essential Factor

When a current of water is to be produced in a pipe, the one thing above all others which must be present in the circuit is the pressure. The pressure in the circuit shown in Fig. 9 is produced by means of the pump. The circuit may be blocked by means of a valve and there will be no current regardless of the value of the pressure. If the valve be opened or the circuit completed, there will be no flow of water in the circuit unless there is a pressure acting in the circuit.

The same general conditions exist in the case of the electrical circuit. If the wire forming the circuit be broken, or if the circuit is opened at a switch, as shown in Fig. 10, there will be no current in the circuit regardless of the value of the pressure. If the circuit be completed, there will be no current unless there is an electrical pressure acting in the circuit. It is thus seen that it is imperative that there must be a pressure acting in every closed circuit in order that there be a current in the circuit.

The electrical pressure for practical purposes on the motor car may be produced by chemical action as in the primary and storage battery, or by electromagnetic induction as in the generator. Both of these methods will be discussed in detail in two of the following sections.

Relation of Current, Pressure and Resistance

The current in an electrical circuit increases with an increase in pressure, provided the resistance of the circuit does not increase in value faster than the pressure. If the resistance of the circuit remains constant, the current in the circuit will increase and decrease directly as the pressure; that is, if the pressure acting in the circuit be doubled, the current in the circuit will be increased to twice the original value, and if the pressure be decreased in value, say, to one-half its original value, the current will decrease in value to one-half its original value.

The current in an electrical circuit decreases with an increase in resistance, provided the pressure in the circuit does not increase in value faster than the resistance. If the pressure in the circuit remains constant, the current in the circuit will vary in value inversely as the resistance of the circuit; that is, if the resistance of the circuit be doubled, the current in the circuit will decrease to one-half of its original value, and if the resistance be decreased in value, say, to one-fourth of its original value, the current will increase in value to four times its original value.

The above relations between current, pressure and resistance are stated as follows:

Current varies as pressure divided by resistance. When the current in the circuit is measured in amperes, the pressure in volts and the resistance in ohms, this relation between current, pressure and resistance may be stated as follows:

$$\text{current} = \text{pressure} \div \text{resistance, or}$$

$$\text{current} = \frac{\text{pressure}}{\text{resistance}}$$

$$\text{amperes} = \text{volts} \div \text{ohms, or}$$

$$\text{amperes} = \frac{\text{volts}}{\text{ohms}}$$

A storage battery is connected to a lamp as indicated in **Fig. 1.** The pressure produced by the battery is 6 volts and the resistance of the lamp is 12 ohms, what current will the battery produce in the lamp? By referring to the above relation between current, pressure and resistance, we see that the current is equal to the pressure in volts divided by the resistance in ohms, and if we replace ''pressure'' by the value of the pressure in volts and ''resistance'' by the value of the resistance in ohms, we may determine the value of the current in amperes as follows:

$$\text{current} = \frac{\text{pressure}}{\text{resistance}}, \text{ or current} = \frac{6}{12} = \tfrac{1}{2} \text{ ampere}$$

If the current in a circuit and the pressure producing the current are both known, then the resistance of the circuit may be determined as follows: Since the current is equal to the pressure divided by the resistance, we may write the resistance equal to pressure divided by the current as follows:

$$\text{resistance} = \text{pressure} \div \text{current, or}$$

$$\text{resistance} = \frac{\text{pressure}}{\text{current}}$$

$$\text{ohms} = \text{volts} \div \text{amperes, or}$$

$$\text{ohms} = \frac{\text{amperes}}{\text{volts}}$$

For example, if the pressure acting in a light circuit of a motor car is 12 volts and there is a current of 4 amperes, then the resistance of the circuit is equal to 12 divided by 4, or

$$\text{resistance} = \frac{12}{4} = 3 \text{ ohms}$$

In some cases the resistance of the circuit and the current it is desired to produce are known and the problem is to find the pressure necessary to produce this desired current. The pressure in a circuit in volts is equal to the resistance of the circuit in ohms multiplied by the current in amperes, or

$$\text{pressure} = \text{resistance} \times \text{current}$$
$$\text{volts} = \text{ohms} \times \text{amperes}$$

For example, if the resistance of a lamp is 3 ohms, what pressure will be required to produce a current of 2 amperes through the lamp? We may determine the value of the pressure required in volts by replacing the resistance in the last equation by the value of the resistance, the current by the value of the current and then multiplying these two quantities, thus

$$\text{Pressure} = 3 \times 2 = 6 \text{ volts}$$

Conductors and Insulators

Some materials will offer less resistance or opposition to the flow of electricity through them than other materials, and for this reason they are called conductors, while those materials which offer a high opposition to the flow of electricity through them are called insulators. For example, copper, iron, brass, carbon, lead, etc., offer a comparatively low resistance to the flow of electricity through them, and hence they are called conductors.

Rubber, glass, fiber, mica, porcelain, etc., all offer a high opposition to the flow of electricity through them, and hence they are called insulators. You must get this fact clearly in mind that all materials will conduct electricity, but the conducting power of some is much better than others, and they are called conductors merely to distinguish them from the materials which are poor conductors of electricity and called insulators. The words conductor and insulator are only relative terms and the readers must not get the impression that some materials will conduct electricity and some will not. In practice, the conducting power of the ordinary insulating materials, such as rubber, porcelain, mica, etc., is so poor in comparison to the conducting power of the conductors, such as copper, brass, iron, carbon, etc., that they are said to conduct no electricity.

Factors Determining the Resistance of a Conductor

The resistance offered by a pipe to the flow of water through it depends upon the size and length of the pipe. The greater the length of the pipe, the greater the resistance it will offer to the flow of water through it, and the shorter the pipe the less the resistance it will offer to the flow of water through it.

The resistance offered by a wire to the flow of electricity through it depends upon the length of the wire just as the resistance of the pipe depends upon the length of the pipe. The longer the wire, the greater the resistance, and the shorter the wire, the less the resistance, the size of the wire, of course, remaining constant. If the length of the wire be increased to twice its original value, its resistance will be doubled, while if its length be reduced, say to one-third its original length, the resistance will be reduced to one-third its original value. In other words, there is a direct relation between the resistance of a wire and its length.

If the area of a pipe be increased; that is, if the pipe be replaced by a smaller one of the same length, there will be an increase in the resistance to the flow of water, while if the area of the pipe be increased there will be a decrease in the resistance. There is a similar relation between the resistance of a wire and its area or size. If a wire of a certain length be replaced by a smaller wire of the same length and of the same kind of material as the first, there will be an increase in the resistance, while if the size of the wire be increased, there will be a decrease in the resistance.

A pump which is producing a certain pressure will cause more water to flow through a short pipe than through a large one of the same size, it also will cause more water to flow through a large pipe than through a small pipe of the same length. Likewise, a battery which produces a certain electrical pressure will cause a greater flow of electricity in a short wire than in a long wire of the same size and of the same material; it also will cause a greater flow of electricity in a large wire than in a small wire of the same length and of the same material.

The relation between the resistance of two wires of the same size and composed of the same material will be exactly the same as the relation between their lengths. That is, if one of the wires is ten times as long as the other one, then its resistance will be ten times as great as the other wire. If two wires are of the same length and composed of the same material but of different size, the relation between their resistances will be just the opposite to the relation between their areas. That is, if one wire has an area three times as large as the other one, its resistance will be one-third as great as that of the other wire.

The resistance of a wire depends upon the kind of material of which the wire is composed. Thus copper is a better conductor of electricity than aluminum; aluminum is better than brass; brass is better than iron; iron is better than lead, etc. A copper wire of a certain size and length will have less resistance than a brass wire of the same size and length; the brass wire will have less resistance than an iron wire of the same size and length, etc.

Since the resistance of a wire increases with an increase in length and decreases with an increase in area, we have the following relation:

The resistance of a wire varies as the length divided by the area. This relation, stated in a little different form, means that the resistance increases at the same rate that the length increases, if the area remains constant, and the resistance decreases at the same rate that the area increases. If the length and area of a wire both increase at the same rate, the resistance of the wire will remain unchanged.

The resistance of a wire is not constant, even though its length and area remain constant, but changes, due to a change in temperature. The change in resistance of some materials due to a change in their temperature is very small, and in some cases may be neglected. Some materials experience an increase in resistance with an increase in temperature, while there is a decrease in resistance with an increase in temperature in some. Carbon, for example, decreases in resistance with an increase in temperature, while the resistance of brass, iron, copper, etc., increases with an increase in temperature. The increase in resistance of a copper wire is approximately $\frac{22}{100}$ of 1 per cent for each degree increase in temperature on the Fahrenheit thermometer. Thus, if a coil of copper wire has a resistance of 100 ohms at 60 degrees, its resistance at 100 degrees may be determined approximately as follows:

Multiply the change in temperature by .0022 and the result by the original resistance, if the temperature is increasing, and the result will be the increase in resistance, thus:

$100 - 60 = 40$ degrees change in temperature
$40 \times .0022 \times 100 = 8.8$ ohms increase
$100 + 8.8 = 108.8$ resistance at 100 degrees

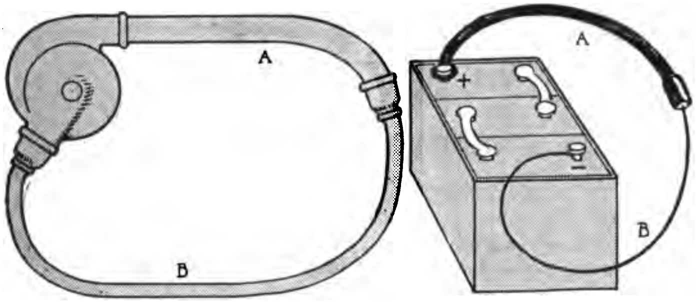
In brief, the resistance of a conductor depends upon three things, and they are:

(a) Dimensions of the conductor (its length and area).
(b) The kind of material in the conductor (whether it is copper, brass, iron, etc.).
(c) The temperature of the conductor.

CHAPTER II

The Series Circuit

IF a water circuit be composed of two pipes and they are connected in the manner indicated at A and B in Fig. 11, they are said to be connected in series. There is only one path through which the water may flow in passing from the outlet of the pump and return to the pump. The current of water at any instant is the same at every point along the two pipes, and just exactly as much water is returning to the pump in a given time as is leaving the pump. The water is not used up in the operation of such a circuit. The circuit is complete and, as in the case of the circle, has neither beginning nor end.



Figs. 11 *and* 12—*A series electrical circuit and a series water circuit compared*

Note that the water is not used up in this operation, but some of its ability to do work is used.

An electrical circuit composed of two or more different wires of perhaps different sizes, lengths and materials, and connected as shown in Fig. 12 is called a series circuit. In this case, there is only one path through which the electricity may flow in passing from the positive terminal of the battery and return to the negative terminal of the battery. The current of electricity is the same at every point along the different wires, and just exactly as much electricity is returning to the battery in a given time as is leaving the battery in the same time.

The electricity is not used up in the operation of such a circuit, but its ability to do work is used, just as in the case of the water. This will be explained more in detail later.

A series water circuit is found in the operation of the cooling system of some early motor car engines, as shown in Fig. 13. In this case, the four waterjackets of the different cylinders, the radiator, the pump and the connecting pipes are all in series. The current of water through the different parts of the circuit at any time is exactly the same; just as much water returns to the pump as the pump sends into the circuit. This method of cooling is not a good one, but is used here for the purpose of bearing out the series circuit idea.

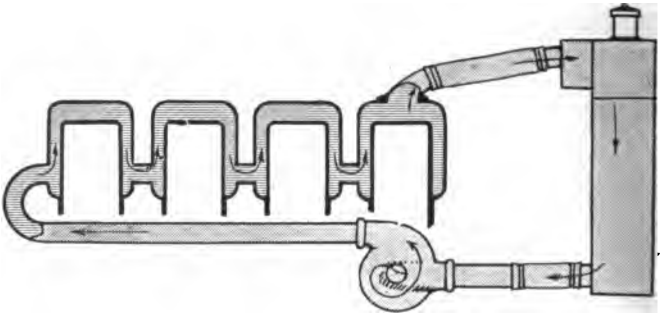


Fig. 13—*A series water circuit as employed on some early cars. The pump, pipes, water jackets and radiator are in series, for the water has only one path in which to flow*

When the headlights on motor cars are connected as shown in Fig. 14, they form a typical series electrical circuit. The current of electricity through the different parts of the circuit at any time is exactly the same; just as much electricity returns to the battery as the battery sends into the circuit. *The electricity is not consumed in the lamps, but some of its ability to light lamps is used.*

Resistance of Series Circuit

Since the resistance offered by a pipe to the free flow of water through it increases with an increase in the length of the pipe, it is evident that the resistance of two pipes connected in series will be greater than the resistance of either pipe alone. If the two pipes are of exactly the same size and length, they will, when connected in series, offer twice the resistance to the flow of water through them that is offered by a single pipe. If the pipes are of the same size but of different lengths, they will offer a combined resistance equal to that of a single pipe of the same size but having a length equal to that of the combined lengths of the two pipes.

Two wires of the same size and material will, when connected in series, offer a combined resistance equal to that of a single wire of the same size, but having a length equal to the combined lengths of the two wires.

Any number of electrical resistances, such as motor car lamps, connected in series might be thought of as being equivalent to a number of wires of the same size and material but having different lengths, and the combined resistance of any number of resistances in series is equal to the sum of the different resistances. For example, if the two lamps in Fig. 14 each have a resistance of 2 ohms, the combination will have a total resistance of 4 ohms. In order to get the total resistance of the circuit, the resistance of the leads, switch, etc., should be added to the resistance of the lamps.

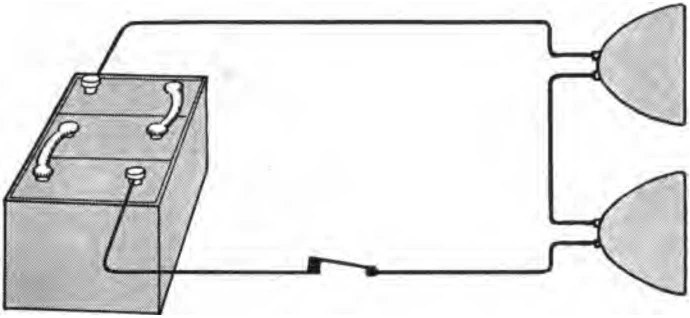


Fig. 14—A series electric lighting circuit. The battery, switch wires and lamps are in series, for the current has only one path in which to flow

Pressure Relations for a Series Circuit

If pressure gauges be connected along a water pipe, as indicated in Fig. 15, in which there is a current of water, the difference in the readings of the different gauges will bear the same relation to each other as exists between the distances between the points to which the gauges are connected. For example, the difference in the reading of gauges G1 and G2 will bear the same relation to the difference in the readings of gauges G2 and G3, as the distance between G1 and G2 bears to the distance between G2 and G3. If the distance between G2 and G3, which we will represent by L2 is twice the distance between G1 and G2, which we will represent by L1, then the difference in readings of G2 and G3 will be twice the difference in the readings of G1 and G2.

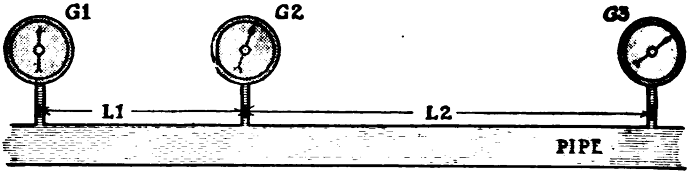


Fig. 15—*The difference in pressure along a water circuit is proportional to the length of the pipe*

The reason for this relation may be explained as follows: Since the resistance between the points where G2 and G3 are connected will be as many times the resistance between the points where G1 and G2 are connected as the length L2 is times the length L1, the pressure between the points where G2 and G3 are connected must be as many times the pressure between the points G1 and G2 are connected as L2 is times L1, in order to produce the current in the pipe. The differences in pressure between different points along a series water circuit will bear the same relation to each other as exists between the resistances between the points where the pressures were measured.

In the electrical circuit, the voltmeter measures the difference in pressure between the points along the circuit to which the terminals of the voltmeter are connected. Thus in Fig. 16 there are two voltmeters connected so as to measure the difference in pressure between two different sets of points. If the wire composing the circuit is of the same material and same size all the way along the circuit, then the reading of the two voltmeters V1 and V2 will bear the same relation to each other as exists betwen the lengths L1 and L2. If the length L2 is twice the length L1, then the resistance R2 is twice the resistance R1, and since the value of the current in R2 is exactly the same as the value of the current in R1—neglecting the current through the voltmeters—there will be twice as much pressure required to produce this current in R2 as is required to produce it in R1, which will result in the reading of V2 being twice the reading of V1. When the resistance R2 is three times the resistance R1, then the reading of V2 will be three times the reading of V1 etc.

The electrical pressure acting on a part of the resistance of a series circuit, bears the same relation to the pressure acting on some other part of the same circuit as exists between the resistance of the two parts. That is, if two resistances are connected in series and they have exactly the same resistance, then the pressure acting on each of them will be exactly the same when there is a current of the same value through them. If, however, two resistances are connected in series and the resistance of one is twice that of the other, then the pressure acting on the one of lower resistance will be one-half of the pressure acting on the one of higher resistance.

If two lamps having different resistances be connected in series, the pressure acting on one lamp will not be the same as the pressure acting on the other lamp. The lamp of higher resistance will have a higher pressure acting on it than the one of lower resistance. This relation accounts for the fact that two lamps of different candlepower and the same voltage will not operate satisfactorily in series, because the one of lower candlepower, or higher resistance, will have a larger part of the total pressure acting on it than the one of high candlepower, or lower resistance. Thus you cannot put a 6-volt, 24-candlepower, headlight in series with a 6-volt, 2-candlepower dashlight, and operate them from a 12-volt battery, but you can put two 6-volt, 24-candlepower headlights or in series with a 12-volt battery, or one 6-volt 2-candlepower dashlight and one 6-volt 2 candlepower taillight in series with a 12-volt battery.

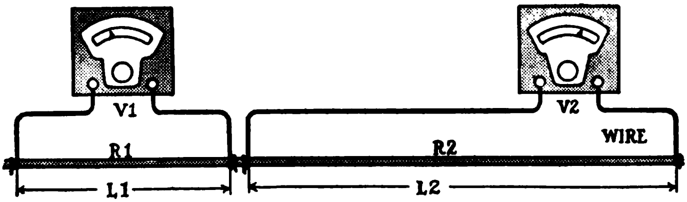


Fig. 16—The difference in pressure along an electrical circuit is proportional to the length of the wire

A 6-volt lamp may be operated on a 12-volt battery by connecting a resistance in series with the 6-volt lamp as shown in Fig. 17. The resistance in series with the lamp must be equal to the resistance of the lamp, in order that the pressure over the lamp be 6 volts or one-half of the total pressure. The pressure over the lamp may be decreased by connecting more resistance in series, or increased by decreasing the amount of resistance in series. This principle is used by some companies in dimming the headlights, as the decrease in pressure on the lamp decreases its candlepower.

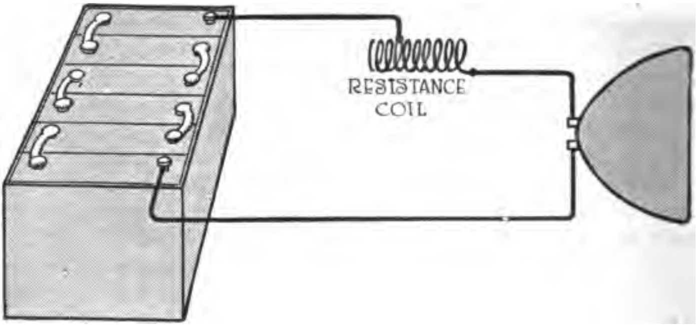


Fig. 17—Using a 6-volt lamp with a 12-volt battery by putting a resistance in series

Current Relations in a Series Circuit

The reader must always have in mind that the current in every part of a series circuit is exactly the same and that there is no accumulation of electricity at any point along the circuit. An ammeter connected at any point in a series circuit will indicate the same current as long as there is no change in the value of the resistance of the circuit or the total pressure acting in the circuit.

If a series circuit be opened at any point by means of a switch, if a lamp burns out or a wire breaks, there will be no current in the circuit and an ammeter connected in the circuit will indicate zero current regardless of where the ammeter may be connected.

The current in a circuit, in amperes, is usually represented by the capital letter I, the pressure in volts by the capital letter E, and the resistance in ohms by the capital letter R.

Examples Illustrating Current Relations

A certain 6-volt headlight takes a current of 4 amperes when it is connected to a pressure of 6 volts. What resistance must be placed in series with the lamp in order to operate it from a 12-volt battery? Since the pressure necessary to operate the lamp is one-half of the total pressure in this case, then the resistance required in series with the lamp will be equal to the resistance of the lamp. The resistance of the lamp, which we will represent by RL, will be equal to the pressure required to operate it divided by the current the lamp takes, or

$$RL = \frac{6}{4} = 1\tfrac{1}{2} \text{ ohms}$$

Therefore the resistance that must be placed in the circuit is 1½ ohms.

If this same 6-volt lamp is to be operated on a 24-volt battery, the procedure in determining the value of the resistance to be placed in circuit is a little different. The resistance and the lamp will carry the same current, since they are in series. The pressure over the resistance which we will represent by ER will be equal to the total pressure, E, of the battery, minus the pressure over the lamp EL or

$$ER = E - EL$$
$$ER = 24 - 6$$
$$ER = 18 \text{ volts}$$

The value of the resistance then is equal to the pressure acting on the resistance divided by the current through the resistance, or

$$R = 18 \text{ divided by } 4 = 4\tfrac{1}{2} \text{ ohms}$$

The resistance of the lamp, if it takes a current of two amperes, is equal to

$$6 \text{ divided by } 4 = 1\tfrac{1}{2} \text{ ohms}$$

It is interesting to note that in each of the above cases, the relation between the resistance of the lamp and the resistance to be connected in series with it is the same as the relation between the pressure acting on the lamp and the pressure acting on the resistance in series with the lamp.

Since the lamp requires a pressure of 6 volts, the pressure acting on the resistance to be placed in series will be the difference between the total pressure, or 24 volts, and the pressure acting on the lamp, or 6 volts, which gives 18 volts. The resistance that must be placed in series with the lamp will be equal to as many times the lamp resistance as the pressure which is to act on the series resistance is times the pressure acting on the lamp. The pressure acting on the series resistance in this case is three times that acting on the lamp, hence, the value of the series resistance must be three times the value of the resistance of the lamp. The resistance of the lamp is equal to the pressure on it divided by the current through it, or 6 divided by 4, or 1½ ohms. Hence, the value of the series resistance will be equal to 3 times 1½ or 4½ ohms.

Pressures in Series

If two pumps be connected as shown in Fig. 18, the pressure produced by one pump will act with the pressure produced by the other pump and the combined pressures of the two pumps will act upon the water circuit to which the combination is connected. Several pumps may be connected in this manner and the sum of the pressures produced by the combination, when they are producing a pressure in the same direction around the circuit, will be equal to the total pressure acting in the circuit. Thus, if each of the pumps indicated in Fig. 18 is producing a pressure of 50 pounds, the total pressure acting in the circuit to which the pumps are connected will be equal to the sum of two pressures or 100 pounds.

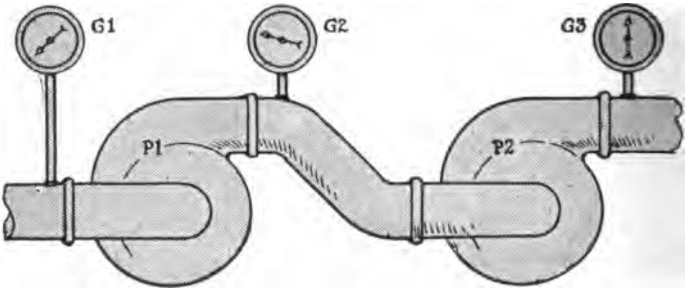


Fig. 18—Boosting the pressure in a water circuit by putting pumps in series

If the pressures produced by the pumps are unequal, the total pressure is equal to the sum of the pressures, just the same. For example, if the pumps are producing pressures of 75 and 25 pounds per square inch, respectively, the total pressure acting on the circuit to which they are connected will be equal to 75 plus 25 or 100 pounds per square inch. If two men shove against a car in the same direction with a force of 100 and 125 pounds, the total force acting on the car is equal to the sum of the two forces or 225 pounds.

Several electrical pressures may be connected in a similar manner to the pumps, as indicated in Fig. 19, which represents two dry cells in series. If the pressure produced by each of the dry cells acts in the same direction, then the total pressure will be equal to the sum of the pressures of the two cells, regardless of whether the pressures produced by the cells are equal or unequal in value. Thus, if the pressures produced by the two dry cells are 1.2 and 1.4 volts, respectively, the total pressure will be equal to 1.2 plus 1.4 or 2.6 volts.

If a number of equal pressures be connected in series so they all act in the same direction around the circuit, then the total pressure will be equal to the product of the number of pressures connected together and the valuě of one of the pressures. For example, if six dry cells, each producing a pressure of 1.5 volts, be connected series, then the total pressure will be equal to six times 1.5 or 9 volts. If ten men are all pushing on a car in the same direction and each is pushing with the same force, say 100 pounds, then the total force acting on the car will be equal to ten times the force of a single man, or 1,000 pounds.

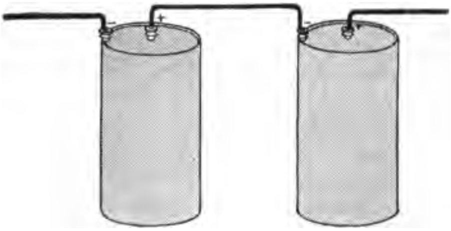


Fig. 19—*Boosting the pressure in an electrical circuit by connecting dry cells in series*

In order that the pressures produced by the pumps act in the same direction around a water circuit, it is necessary to connect the sides of the pumps of lower pressure to the sides of higher pressure in regular order. If pressure gauges be connected to the circuit as indicated in Fig. 18, it is possible to determine the pressure produced by either of the pumps or any combination by observing the indic tions of the proper gauges.

For example, the pressure produced by the pump P1 is equal t the difference in the pressure before and beyond the pump, whic may be determined by reading the gauges G1 and G2 and then subtracting the lower reading from the higher reading. The pressur produced by the pump P2 may, in a similar manner, be determine by taking the difference in the readings of the gauges G2 and G3. The pressure produced by each pump tends to cause the water to flow through the pump itself from the terminal of lower pressure toward the terminal of higher pressure, and through the water circuit to which the pump is connected from the terminal of higher pressure toward the one of lower pressure. All of the pumps will be acting in the same direction when the pressure gauges on, say the right-hand side of the different pumps, all read higher than the pressure gauges on the left-hand side, or all of the gauges on the left-hand side read higher than all of the gauges on the right-hand side.

If some of the pumps are connected in the circuit so that the pressure they produce is opposed to the pressure produced by the other pumps, then the pressure acting in the circuit will be equal to the difference between the sum of the pressures acting in one direction and the sum of the pressures acting in the other direction. If the sum of the pressures acting in one direction is exactly equal to the sum of the pressures acting in the opposite direction, then the pressure acting in the circuit tending to produce a flow of water will be equal to zero.

The direction of the pressure acting in the circuit when there are pressures in both directions, will correspond to the larger sum. For example, if six pumps are connected in such a manner that the pressure produced by two of them is in the opposite direction to the pressure produced by the remaining four, it is obvious that the pressure acting in the circuit to which the pumps may be connected is not equal to the sum of the pressures produced by all six pumps, but it is equal to the difference in the sum of the pressures produced by the four pumps and the sum of the pressures produced by the two pumps.

If each of the six pumps is producing a pressure of 10 pounds, the pressure acting in the circuit may be determined as follows: The pressure produced by the four pumps will be equal to the pressure produced by a single pump multiplied by four, or 10 × 4, or 40 pounds. The pressure produced by the two pumps likewise is equal to 10 × 2, or 20 pounds.

The pressure acting in the circuit is equal to the pressure in one direction subtracted from the pressure in the opposite direction, or $40 - 20 = 20$ pounds. The direction of this pressure of 20 pounds will be the same as the direction of the larger sum of 40 pounds. The same results could be accomplished by using two pumps alone instead of six, as the pressure of two of the six pumps which are acting in one direction is exactly neutralized by the pressure of two of the six pumps acting in the opposite direction.

It is obvious that if ten men are pushing on a car—say, six in a certain direction and four in an exactly opposite direction—that the force tending to move the car is not equal to the combined forces produced by the ten men but it is equal to the force produced by the six men minus the force produced by the four men or $600 - 400 = 200$ pounds. The direction of this resultant force corresponds to the direction in which the six men are pushing.

In order that the electrical pressures produced by several batteries may act in the same direction around the electrical circuit, it is necessary that the terminal of lower electrical pressure of one battery be connected to the terminal of higher pressure of the next battery; that is, that the negative terminal of one battery be connected to the positive terminal of the next one. The pressure produced by the battery causes the electricity to pass through the battery itself from the terminal of lower pressure, or negative terminal, toward the terminal of higher pressure, or positive terminal, while in the part of the electrical circuit outside of the battery it causes the electricity to pass from the terminal of higher pressure toward the terminal of lower pressure.

The action of a generator is exactly the same as the battery, inasmuch as the current is from the negative to the positive terminal within the generator and from the positive to the negative terminal through the circuit outside the generator. If several electrical pressures be connected in series in such a manner that part of them are acting in one direction around the electrical circuit and the remainder in the opposite direction, the total pressure acting in the circuit will not be equal to the sum of all the different pressures, but it will be equal to the difference in the sums of the pressures acting in the opposite directions.

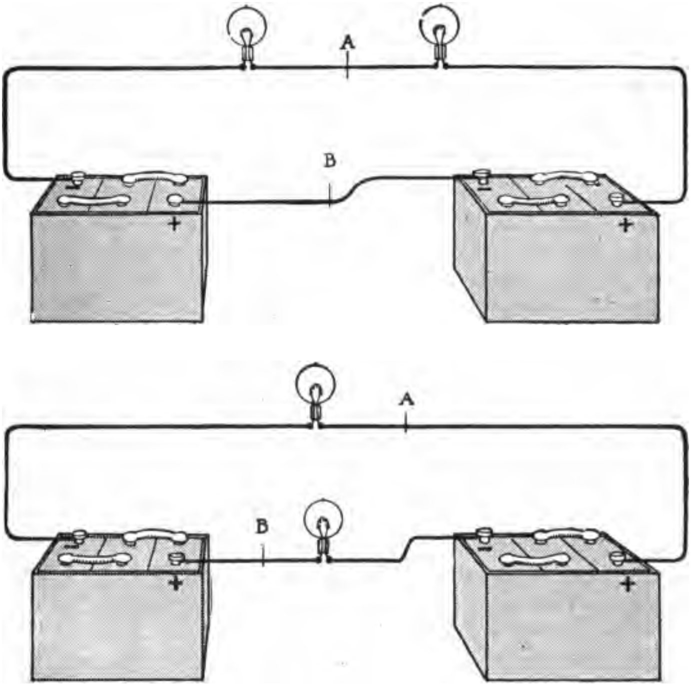
The difference in the sum of the pressures acting in the two directions around the circuit is called the *effective pressure* and the direction of the effective pressure will correspond to the direction of the larger sum of pressures. For example, if six dry cells each producing a pressure of 1.5 volts, are connected in series, but the pressure produced by two of them is in the opposite direction to the pressure produced by the remaining four cells, then the effective pressure in the circuit will be equal to the pressure produced by the four cells, or 6 volts, minus the pressure produced by the two cells, or 3 volts, which gives 3 volts. The same effective pressure could be produced by two cells acting alone, as the pressure produced by two of the six cells acting in one direction is exactly counteracted by the pressure of two of the six cells acting in the opposite direction.

Arrangement of the Parts of a Series Circuit

The order in which the various parts of a series circuit are arranged has nothing to do with the operation of the circuit. The pressures may be connected together at one point and the resistances all connected directly together, or the pressures may be distributed around the circuit by connecting the resistances between the different pressures. The effective pressure acting in the series circuit is independent of the location of the various pressures in the circuit and, likewise, the total resistance of the circuit is independent of the location of the different resistances forming the circuit. Two 6-volt lamps and two 6-volt batteries may be connected in series as shown in Fig. 20 or they may be connected as shown in Fig. 21 and the results are exactly the same.

If a voltmeter be connected between the points A and B in Figs. 20 and 21 there will be no indication of pressure between the two points and so far as the operation of the circuit is concerned they may be connected together. The reason for there being no difference in pressure between the points A and B is as follows: The same part of the total pressure is used in operating each of the lamps, since they are supposed to have the same resistance, and, since the pressure produced by each of the batteries is the same, we can think of one of the batteries as producing the current in one of the lamps and the other battery as producing the current in the other lamp.

If the lamps were of unequal resistance, in Figs. 20 and 21, and the pressures produced by the batteries were the same, there would be a difference in pressure between the points A and B; or, if the resistances of the lamps were the same and the pressures produced by the batteries were unequal, there would be a difference in pressure between the points A and B. If, however, the resistances of the lamps are unequal and the pressures produced by the batteries are also unequal, but the relation between the resistances is the same as the relation between the pressures produced by the batteries, then there will be zero pressure between the points A and B, if these points are so chosen that the lamp of higher resistance is in circuit with the battery of higher pressure between the two points.



Figs. 20 *and* 21—*Two methods of connecting lamps and batteries in series*

Internal Resistance

Part of the pressure produced by a pump, when it is causing the water to flow through a water circuit is used in causing the water to flow through the pump itself. The property of the pump which results in part of the pressure it produces being used in the above manner may be called the internal resistance of the pump. The greater the current of water through the pump, the greater the pressure required to overcome the internal resistance of the pump.

When there is no current through the pump the difference in the pressure indicated by two gauges connected to the terminals of the pumps will represent the total pressure produced by the pump. The part of this total pressure which is available to act on the external circuit and produces a current will depend upon how much of it is used within the pump itself. It is obvious that the pressure between the terminals of the pump when there is a certain current through it will be greater for a low internal resistance than for a high internal resistance. Hence, it is desirable to have the internal resistance of the pump as low as possible in order that just as much of the pressure it produces be available at the terminals of the pump. The pressure between the terminals of the pump will change as the current through the pump changes even though the total pressure produced by the pump remains constant. The larger the current through the pump the lower the difference between the terminal pressures.

All of the pressure produced by the battery or generator is not available at the terminals, as a part of the pressure is used in causing the electricity to flow through generator or battery. The opposition offered by the generator or battery to the flow of electricity through it is called the *internal resistance.* The action of the internal resistance of the generator or battery is exactly the same as the internal resistance of the pump. It results in the pressure between the terminals of the generator or battery decreasing as the value of the current through them increases, assuming the total pressure generated remains practically constant. A few simple examples will perhaps give the reader a better understanding of the effect of this internal resistance upon the operation of the electrical circuit.

The total pressure generated in a certain storage battery is 6.8 volts and the internal resistance of the battery is .04 ohm. What will be the pressure between the terminals of the battery when the battery is supplying a current of 20 amperes?

The pressure required to produce a current of 20 amperes through a resistance of .04 is equal to the product of the current and the resistance, .04 × 20, or .8 volt. The pressure available at the terminals of the battery will be equal to the total pressure minus the pressure required to produce the current through the internal resistance, or 6.8 minus .8, or 6 volts.

If several batteries similar to the above be connected in series so that their pressures are all acting in the same direction around the circuit there will be a decrease in the value of the pressure between the terminals of each of the batteries as the current in the circuit increases in value. The decrease in pressure of the different batteries will be the same provided their internal resistances are equal in value. If the internal resistance of the different batteries are not equal, there will be a greater decrease in the value of the pressure between the terminals of the batteries of larger internal resistance than between the terminals of the batteries of lower internal resistance.

It may happen that the internal resistance of one or more of the batteries is such that the pressure required to cause the electricity to flow through its internal resistance is greater than the pressure produced by that particular battery, which results in a part of the pressure produced by some other battery of lower internal resistance being used to cause the electricity to flow through the battery of higher internal resistance.

This state of affairs may exist in a circuit composed of a number of dry cells connected in series. The pressure produced by each of the dry cells may be the same when measured by means of a voltmeter and there is no current through them except that required to operate the voltmeter. If a current be taken from each of the cells, it will be observed that there is a decrease in the voltmeter reading due to a part of the total pressure being used within the cell. The internal resistance of some of the cells may be such that it will be impossible to get a very large current from the cells even if their terminals be connected directly to the ammeter. A cell of high internal resistance may do more harm in a circuit than it does good.

For example, when the pressure required to cause the electricity to flow through the internal resistance is greater than the pressure the cell is producing, the cell is a hindrance rather than an aid to the operation of the circuit. All of the cells may help in producing the current, when the value of the current is small, but with an increase in current some of the cells may prove to be worthless or a hindrance to the operation of the circuit.

The above discussion leads to the conclusion that the condition of a cell cannot be determined by measuring its pressure alone, but the ability of the cell to deliver current or the decrease in pressure between its terminals with an increased in current must be determined. A more detailed discussion of the internal resistance of a cell will be given in the section on batteries.

Calculating Resistance for Battery Charging

A storage battery is charged by sending a current through the battery from the positive to the negative terminal or just opposite to the direction in which the pressure of the storage battery acts. The pressure producing the current must be ample to overcome the pressure of the storage battery and in addition to produce the required current through the resistance of the connecting leads and the internal resistance of the battery. In some cases the pressure producing the current is varied in value in order to produce the required current, while in some cases the pressure of the source from which the charging current is derived remains constant and the resistance of the circuit is adjusted so as to give the proper current.

For example, what resistance must be connected in circuit, if it is desired to send 4 amperes through a 6-volt battery when it is connected to a 110-volt circuit? If the pressure produced by the battery is exactly 6 volts and the pressure of the circuit to which the battery is connected is 110 volts, then the effective pressure is equal to 110 minus 6, or 104 volts. This effective pressure of 104 volts is to produce a current of 4 amperes, therefore the resistance of the circuit must be equal to 104 divided by 4, or 26 ohms. This resistance of 26 ohms represents the total resistance of the circuit. If the pressure of the battery increases, the current in the circuit will decrease as the effective pressure will be less. In order to maintain the current constant in value, as the value of the effective pressure decreases, it will be necessary to decrease the resistance of the circuit.

If several batteries be connected in series, the effective pressure will be less than in the case of a single battery, and hence less resistance will be required in order that the current be the same in both cases. Details for charging storage batteries will be given in the section on batteries.

CHAPTER III

Parallel Circuits

IF a water circuit is composed of two pipes and they are connected in the manner indicated at A and B in Fig. 22, they are said to be connected in parallel or multiple. There are two paths in which the water may flow in passing along the circuit from the point A to the point B and just as much water is returning to the pump in a given time as to leaving it. The quantities of water passing through the different pipes in a given time or the currents of water in the different pipes connected in parallel are not necessarily equal unless the resistances of the different pipes are the same. The water is not used up in the operation of such a circuit.

An electrical circuit composed of two or more different wires of perhaps different sizes, lengths and material, and connected as shown in Fig. 23, is called a multiple or parallel circuit. In this case there are as many paths for the electricity to flow through in passing from the positive terminal to the negative terminal, through the circuits outside the battery, as there are different wires in parallel. Just as much electricity is returning to the battery in a given time as is leaving the battery. The quantities of electricity passing through the different paths in one second or the currents in the different paths of the parallel circuits are not necessarily equal unless the resistance of the different paths is the same. Just remember that the electricity is not used up in the operation of such a circuit.

A parallel water circuit it is found in the operation of the cooling system of a motor car engine, as shown in Fig. 24. In this case, the water jackets of the four cylinders are all connected in parallel and the pump forces the water through the water jackets and radiator. The current of water through the pump and radiator is the same and equal to the combined currents through the four water jackets. The currents in the different water jackets are not necessarily equal unless the opposition offered to the flow of water through the different jackets to the same in each case. It is obvious that, if the water jacket of one cylinder offers a greater opposition to the flow of the water than the other water jackets, there will be a smaller current through this jacket than through the others.

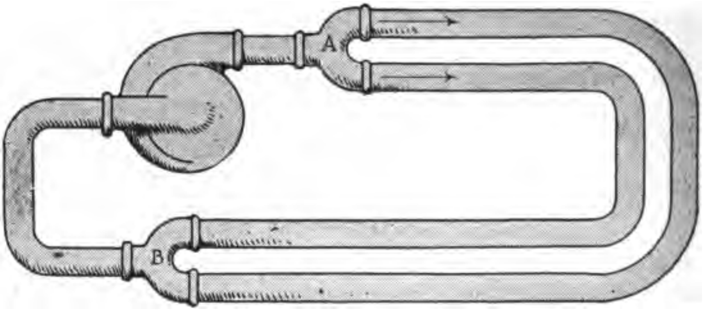


Fig. 22—*A parellel water circuit*

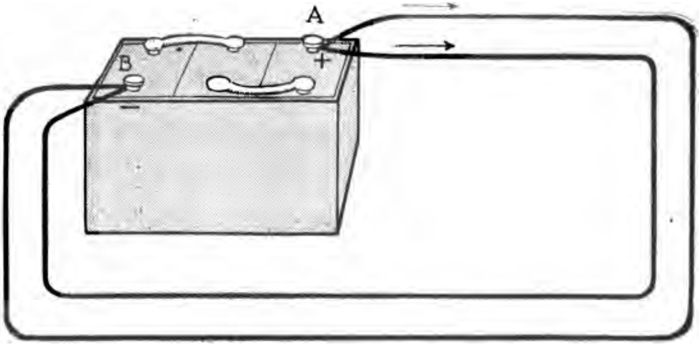


Fig. 23—*A parallel electric circuit*

The water jacket offering the greatest opposition to the flow of water will have the smallest current; while the water jacket offering the smallest opposition always will have the largest current. The current in the remaining paths will have a value somewhere between the above maximum and minimum values.

When the headlights on a motor car are connected as shown in Fig. 25, they form a typical parallel electrical circuit. Just as much electricity returns to the battery in a given time as leaves the battery. The current in each of the lamps is not necessarily the same. Remember the electricity is not consumed in the lamps.

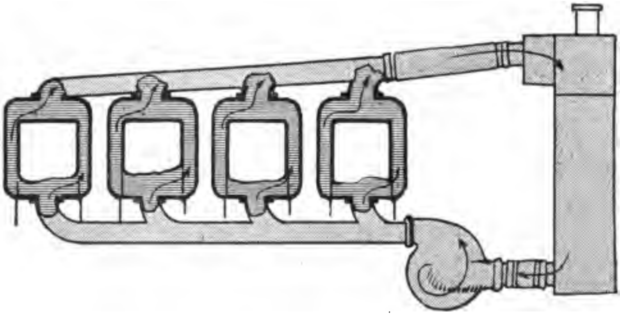


Fig. 24—Parallel water circuit in car's cooling system

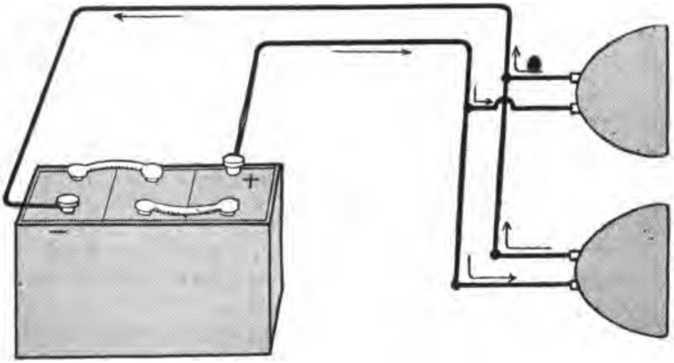
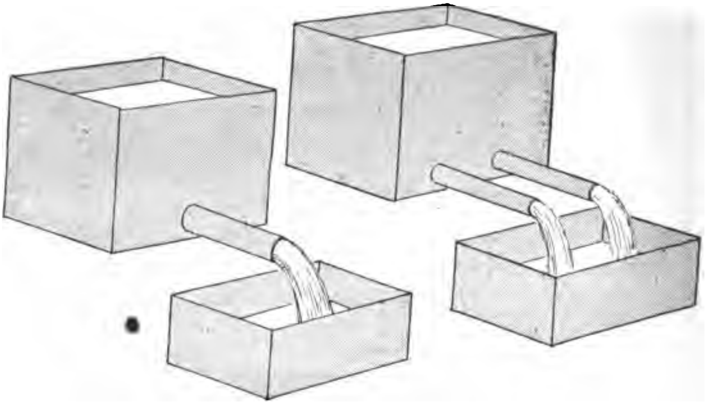


Fig. 25—Parallel electric circuit in lighting system

Resistance of Parallel Circuits

Since the resistance offered by a pipe to the free flow of water through it decreases with an increase in the size of the pipe the length remaining constant, it is evident that the resistance offered by two pipes connected in parallel will be less than the resistance of a single pipe. If the two pipes are of exactly the same size and length, they will, when connected in parallel, offer one-half of the resistance to the flow of water through the circuit that is offered by a single pipe.

For convenience, the two pipes, as shown in Fig. 26, might be considered as being equivalent to a single pipe, as shown in Fig. 27, whose length is the same as that of each of the two pipes and whose area is equal to the combined area of the two pipes, which will be twice that of either pipe, since the pipes are equal in area. The resistance of this large pipe, which is to replace the two smaller ones, will be one-half of that of either of the single small pipes since its area is equal to twice the area of either of the two small pipes.



Figs. 26 and 27—The two pipes, at right, have the same resistance as one pipe, at left, if the combined areas of the two small pipes are equal to the area of the large pipe

Two wires of the same size and length and of the same material will, when connected in parallel, offer a resistance which is equal to the resistance of a wire of the same material and having the same length but having an area equal to twice the area of either wire. Thus the resistance of two wires of the same dimensions and material will offer, when connected in parallel, one-half of the resistance of either wire alone. Any number of electrical resistances connected in parallel might be thought of as being equivalent to a number of wires of the same length and material but having the same or different areas. Their combined resistance then will be equal to the resistance of a single wire of the same material and same length and whose area is equal to the sum of the areas of the several different wires.

For example, if two resistances of 6 and 3 ohms, respectively, be connected in parallel, their combined resistance may be determined as follows:

For convenience, let us assume that these two resistances are two wires of the same material and that they are equal in length. Then, the area of the 3-ohm wire will be twice the area of the 6-ohm wire, since its resistance is one-half as great, the area increasing as the resistance decreases. The two wires will have a combined area equal to three times the area of the 6-ohm wire. The resistance of a wire whose area is three times that of another wire of the same material and having the same length will be one-third of the resistance of the smaller wire.

Hence, the resistance of a wire which may replace the two wires is equal to one-third the resistance of the 6-ohm wire, or 2 ohms.

Suppose three resistances of 4, 3 and 12 ohms, respectively, be connected in parallel. Their combined resistance may be determined as follows:

Again let us assume that these resistances are three wires of the same material and all have the same length, then the area of the 4-ohm wire will be three times as great as the area of the 12-ohm wire and the area of the 3-ohm wire will be four times as great as the area of the 12-ohm wire.

The three wires will have a combined area equal to $1 + 3 + 4$ or 8 times the area of the 12-ohm wire. This equivalent wire whose area is 8 times the area of the 12-ohm wire will have a resistance equal to one-eighth of the 12-ohm wire or 1½ ohms.

Any number of resistances may be combined in the above manner by first assuming them all composed of the same material and having the same length and then replaced by a wire of the same material and same length, but having an area equal to the combined area of the several wires.

Conductance

The resistance of the electrical circuit is a property of the circuit which opposes the free flow of electricity through the circuit, and it is measured in a unit called the ohm. The property of the circuit which permits the electricity to flow, or that property which is just the opposite of resistance and is equal to 1 divided by the resistance in ohms, is called the conductance of the circuit and it is measured in a unit called the *mho.* It is interesting to note that the unit in which the conductance is measured is the unit of resistance, the ohm, spelled backward.

The resistance of a parallel circuit may be determined by merely adding the conductances of the several parts just as the resistance of a series circuit may be determined by adding the resistances of the different parts. For example, if two resistances of 6 and 3 ohms, respectively, are connected in parallel their resistance may be determined as follows: The conductance of the 6-ohm branch will be equal to 1 divided by 6, or 1/6 mho, and the conductance of the 3-ohm branch will be equal to 1 divided by 3, or ⅓ mho. The total conductance of the divided circuit will be equal to the sum of the conductances of the two branches, or

$$\text{total conductance} = 1/6 + 1/3 = 3/6 \text{ mho}$$

Since the conductance of a circuit is equal to 1 divided by the resistance then the above relation may be written as follows:

$$\frac{1}{\text{resistance}} = 3/6$$

$$\text{or the resistance} = 6/3 = 2 \text{ ohms}$$

Suppose three resistances of 6, 3 and 12 ohms, respectively, be connected in parallel, then their combined resistance may be determined as follows:

$$\begin{aligned} \text{total conductance} &= \tfrac{1}{4} + \tfrac{1}{12} + \tfrac{1}{3} \\ &= \tfrac{3}{12} + \tfrac{1}{12} + \tfrac{4}{12} \\ &= \tfrac{8}{12} \text{ mho} \end{aligned}$$

$$\text{Then } \frac{1}{\text{resistance}} = \tfrac{8}{12}$$

$$\text{or the resistance} = \tfrac{8}{12} = 1\tfrac{1}{2} \text{ ohms}$$

If two headlights whose resistance are 4 and 2 ohms respectively be connected in parallel, what will be the value of their combined resistance? The conductance of the two branches of the divided circuit formed by the two lamps will be one-fourth and one-half mho respectively, and the total conductance will be

$$\begin{aligned}\text{total conductance} &= \tfrac{1}{4} + \tfrac{1}{2} \\ &= \tfrac{1}{4} + \tfrac{2}{4} \\ &= \tfrac{3}{4}\text{ mho}\end{aligned}$$

$$\text{then } \frac{1}{\text{resistance}} = \tfrac{3}{4}$$

$$\text{or, the resistance} = \tfrac{4}{3} = 1\tfrac{1}{3}\text{ ohms}$$

Therefore the two lamps will have a combined resistance of $1\frac{1}{3}$ ohms.

When any number of equal resistances are connected in parallel the total resistance is equal to the resistance of one of the resistances divided by the number of resistances connected in parallel. For example, if six 4-ohm lamps are connected in parallel the total resistance of the combination will be equal to 4 divided by 6, or $\frac{2}{3}$ ohm. Remember this method of determining the resistance of a parallel circuit holds true only when the value of the different resistances is the same.

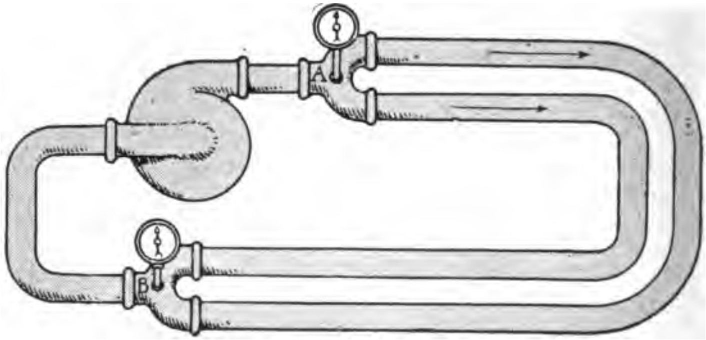
Pressure Relations for the Parallel Circuit

If pressure gauges be connected to the water circuit at the points A and B as indicated in Fig. 28, the difference in the readings of the two gauges will represent the pressure acting on each of the pipes forming the parallel circuit. It is obvious, from an inspection of this figure, that the pressure acting on each of the branches of a parallel or divided circuit is at each instant exactly the same.

If a voltmeter be connected to the electrical circuit at the points A and B as indicated in Fig. 29, the pressure indicated by the voltmeter will represent the value of the pressure acting on the divided circuit, and, it is obvious that the pressure acting on each of the several branches of a parallel circuit at any instant is exactly the same, since each branch is connected between the same two points. If several lamps be connected in parallel, the pressure acting on each of the lamps will be the same regardless of their candle-power or voltage ratings.

Current Relations for the Parallel Circuit

If two pipes of the same size and same length be connected in parallel and the combination in turn connected to a pump, the current of water in each of the pipes will be the same since they each offer the same resistance and the same pressure is acting on each of them. If, however, one of the pipes be longer than the other, their size being the same; or if one pipe be smaller than the other, their lengths being the same, the current of water in the two pipes will not be the same. The current of water in the pipes which offers the greater resistance will be less than the current of water in the pipe which offers the less resistance. For example, if the resistance of one pipe is twice as great as the resistance of the other pipe, then the current in it will be one-half as great as the current in the other pipe.



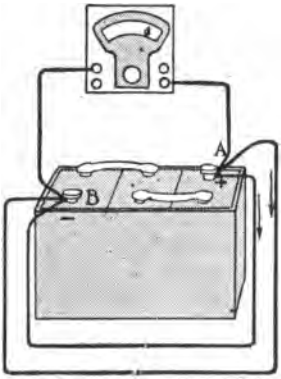


Fig. 29—The voltmeter across the ends of the branches in a parallel electric circuit shows the pressure in each branch, since the pressure is the same in each branch

Fig. 28—The difference of the readings of the two pressure gauges at either end of the parallel water circuit represents the pressure on each pipe

If two equal electrical resistances be connected in parallel they will each carry the same current. For example, if two 12-volt headlights of the same make and same candlepower be connected in parallel to a 12-volt battery, the current in each of the lamps will be practically the same. The total current supplied by the battery will be equal to the sum of the currents in the two branches. If, however, two resistances which are unequal in value be connected in parallel the current in the resistances will not be the same.

The branch of the divided circuit having the larger resistance will carry the smaller current, while the branch of the divided circuit having the smaller resistance will carry the larger current. The total current supplied to the divided circuit will be equal to the sum of the currents in the two branches regardless of whether these are equal or not. Thus if two 6-volt lamps which take currents or 3 and 2 amperes respectively be connected in parallel to the terminals of a 6-volt battery, the total current taken by the lamp will be equal to 3 plus 2 or 5 amperes.

From the above discussion it is obvious that lamps made to operate on different voltages can not be operated satisfactorily in parallel, because, if the voltage is adjusted to the proper value for one lamp, it is not correct for the other. In the case of the series circuit, the lamps had to take the same current in order to operate satisfactorily in series.

The relation of the currents in the two branches of a divided circuit is just the reverse of the relation between the resistances of the two branches. Thus, if the resistances of the two branches of a divided circuit are 4 and 8 ohms, respectively, then the current in the 4-ohm branch will be twice as great as the current in the 8-ohms since the resistance of the 4-ohm branch is one-half the resistance of the 8-ohm branch.

The total current supplied to a parallel circuit of any number of branches is equal to the sum of the currents in all of the different branches, and the relation of the currents in the different branches is just the reverse of the relation of the resistance of the different branches.

Examples Illustrating Relations of Parallel Circuits

If three resistances of 6, 3 and 2 ohms respectively are connected in parallel the relation of the currents in the different branches will be as follows: The current in the 2-ohm resistance will be equal to three times the current in the 6-ohm resistance and one and one-half times the current in the 3-ohm resistance. The current in the 3-ohm resistance will be equal to twice the current in the 6-ohm resistance and two-thirds of the current in the 2-ohm resistance. The current in the 6-ohm coil will be equal to one-half of the current in the 3-ohm coil and one-third of the current in the 2-ohm coil.

The resistance of the winding of an electric heater which is made to operate on a 12-volt battery is 3 ohms. What will the resistance of this heater be if a second winding of 6 ohms is connected in parallel with the first winding and what current will the heater take from a 12-volt battery after the second winding is put in place?

The combined conductance of the two windings is equal to

$$\frac{1}{3}+\frac{1}{6}=\frac{2}{6}+\frac{1}{6}=\frac{3}{6}\text{mho}$$

then the resistance will be equal to 6 divided by 3, or 2 ohms.

The current taken by the 6-ohm winding will be equal to 12 divided by 6 or 2 amperes, and the current taken by the 3-ohm winding will be equal to 12 divided by 3 or 4 amperes. The total current taken by the heater after the second winding is put in place, will be equal to the sum of the currents taken by the two windings, that is 2 + 4 or 6 amperes.

The total current can be obtained by dividing the pressure acting on the heater by the combined resistance of the two windings, as follows:

$$1 = \frac{12}{2} = 6 \text{ amperes}$$

Combined Series and Parallel Circuits

An electrical circuit may be a combination of one or more series and parallel circuits, as shown in Fig. 30, which represents two headlights in parallel with each other and this combination in turn connected in series with a resistance R and a storage battery. This is the principle used in some methods of dimming headlights. The sum of the currents through the two lamps is equal to the total current or the current in the resistance. The total resistance of this circuit is equal to the sum of the resistance of the parallel portion and the resistance of the remainder of the circuit. For example, if the resistance of the two lamps is 4 ohms each and the resistance of the coil in series is 3 ohms, the total resistance can be determined as follows:

Since the two lamps have equal resistances, their combined resistance will be equal to 4 divided by 2 or 2 ohms, and the total resistance will be equal to 2 plus 3 or 5 ohms.

If the voltage of the battery is 6 volts, the current in the circuit will be equal to 6 divided by 5 or 1.2 amperes. The value of the current in each of the lamps will be the same, since the two paths of the divided circuit have the same resistance, or one-half of 1.2, or .6 ampere. The pressure over the two lamps in parallel will be the same part of the total pressure as the resistance of the two lamps in parallel is a part of the total resistance. The resistance of the two lamps in parallel is 2 ohms and the total resistance is 5 ohms. Hence, the pressure over the lamps will be equal to 2/5 of 6 or 2.4 volts.

The pressure over the 3-ohm resistance will be equal to 3/5 of 6 or 3.6 volts. Or, if the drop over one part of the circuit is known the drop over the other part will be equal to the total pressure minus the drop over the first part. Thus the drop over the two lamps in parallel is 2.4 volts. Then, the drop over the 3-ohm resistance will be equal to 6 minus 2.4 or 3.6 volts.

Pressures in Parallel

If two pumps be connected, as shown in Fig. 31, they are said to be connected in parallel and the sum of the currents of water through the two pumps will be equal to the total current in the main pipes

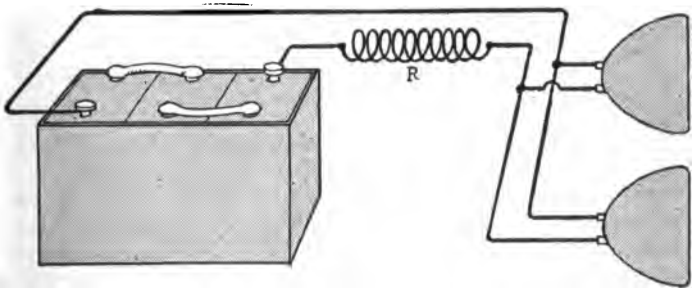


Fig. 30—A combined series and parallel lighting circuit, in which the lamps are in parallel and a resistance coil in series with the battery

and water motor M, provided the currents in the two pumps are both in the same direction, that is, say from the point A to the point B, as indicated.

Let us assume that the valve V in the main circuit is closed so that there is no current through the water motor M. If the pressures produced by the two pumps are exactly equal and in the same direction with respect to the junction points A and B in Fig. 31, there will be no current through either pump because the two pressures are equal and neutralize each other. If, however, the pressure produced by one pump is less than that produced by the other pump, the two pressures no longer neutralized and there will be a current produced through both pumps by an effective pressure which will be equal to the difference in the pressures produced by the respective pumps.

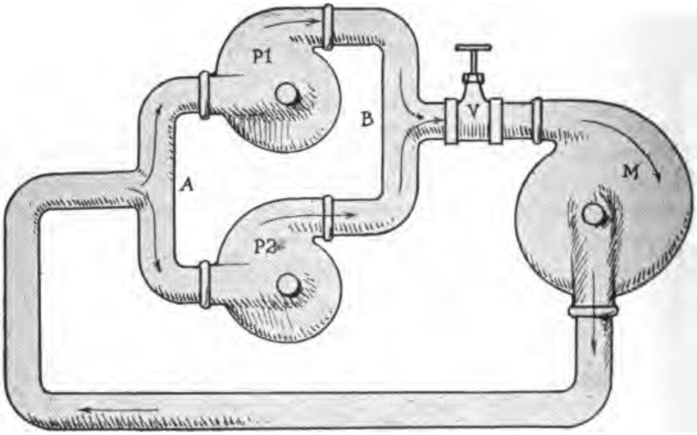


Fig. 31—*Water pressures in parallel. Two pumps,* P1 *and* P2, *supply one motor M*

For example, suppose the pressure produced by the upper pump is less than the pressure produced by the lower pump, then there will be an effective pressure acting around the circuit composed of the two pumps and their connecting pipes in the direction of the arrows through P2.

The current in the upper pump will be in a direction through that pump opposite to the direction of the pressure the pump itself is producing; while in the lower pump the direction of the current will be the same as the direction of the pressure that pump is producing. The current will be in the same direction as the arrows through P1 if the pressure produced by the upper pump is greater than the pressure produced by the lower pump.

The pressure between the two points A and B will be equal to the pressure produced by either or both pumps, provided there is no current in either or both of the pumps. When there is a current through either or both of the pumps and if this current is in the same direction as the pressure produced by the pump, the pressure between the terminals of the pump or between the points A and B will be equal to the total pressure produced by the pump less the pressure required to force the water through the circuit between the points A and B or to overcome the internal resistance of the pump.

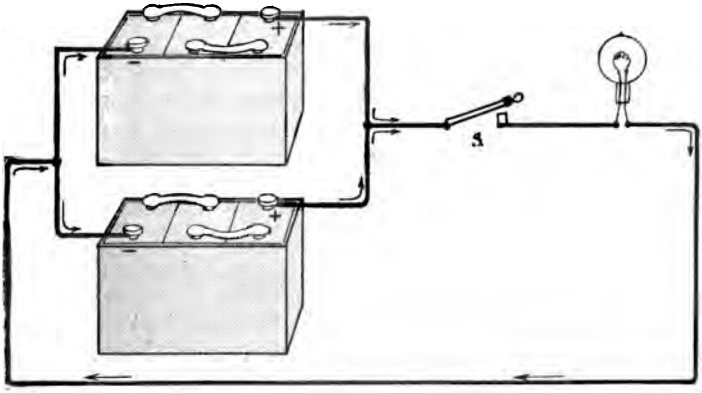


Fig. 32—Electrical pressures in parallel. Two batteries supply one lamp

If the current through the pump is in the opposite direction to the pressure produced by the pump, the pressure between the terminals of the pump or between the points A and B will be equal to the total pressure produced by the pump plus the pressure required to force the water through the circuit between the point A and the point B or to overcome the internal resistance of the pump.

It is obvious from the above discussion that the operation of two pumps having different internal resistances and producing different pressures would not be very satisfactory.

Two batteries are shown connected in parallel in Fig 32 and arranged to supply current to a 6-volt lamp. When the electrical pressure produced by the two batteries is the same and the two positives are connected together and the two negatives together, there will be no current through either of them when the switch S in the main circuit is open. If, however, the pressure produced by one battery is greater than that produced by the other, then there will be a current through both batteries when the outside circuit is open.

Suppose, for example, the pressure produced by the lower battery is greater than the pressure produced by the upper battery. Then, there will be a current through the upper battery in a direction opposite to its own pressure, even though there be no current in the main circuit. If the value of the current in the main circuit be increased gradually there will be a decrease in the terminal pressure of the batteries, but the one of higher pressure will send a current through the one of lower pressure and also the current through the main circuit.

As the current in the main circuit increases, the terminal pressure of the batteries will continue to decrease and finally this pressure will be equal to the pressure produced by the upper battery. Then, there will be no current through the upper battery. While there is a current through the upper battery in a direction opposite to its own pressure, the battery is doing more harm than good, so far as the main circuit is concerned. If the current in the main circuit further increases, the terminal pressure between the points A and B will decrease and there will be a current in the upper battery in the same direction as the pressure of that battery.

Suppose two batteries whose pressures are 6.5 and 7 volts, respectively, and whose internal resistances are .01 and .015 ohm, respectively, are connected in parallel as indicated in Fig. 33. What current will there be in each battery, when the main circuit is open?

The pressures produced by the two batteries are in opposition to each other, but they will not be neutralized, as they are not equal in value, and, as a result, there will be an effective pressure acting in the circuit, composed of the two batteries and their connecting leads, equal in value to the difference between the pressures of the two batteries, which is equal to 7.0 minus 6.5 or .5 volt. Neglecting the resistance of the connecting leads, this effective pressure is acting in a circuit whose combined resistance is equal to the sum of internal resistances of the two batteries, which is .010 plus .015 or .025 ohm. There will be a current produced whose value is equal to the effective voltage divided by the resistance, or

$$\text{current} = .5 \div .025 = 20 \text{ amperes.}$$

Hence, the 7-volt battery will charge the 6.5-volt battery at a 20-ampere rate, when there is no current in the main circuit.

The current in the 6.5-volt battery will be zero when the terminal voltage of the 7-volt battery is 6.5 volts. In order that the terminal voltage of the 7-volt battery be 6.5 volts, .5 volt must be used within the battery itself in overcoming the internal resistance of the battery. This .5 volt pressure will produce a current whose value is equal to this pressure divided by the internal resistance of the battery, or

$$\text{current} = .5 \div .015 = 33\tfrac{1}{3} \text{ amperes.}$$

Hence, the current in the 6.5-volt battery will be zero when the current in the main circuit is 33⅓ amperes. The 6.5-volt battery will be charging from the 7-volt battery for all values of current in the main circuit up to 33⅓ amperes. When the current in the main circuit exceeds 33⅓ amperes, both batteries act together to produce a current in the main circuit, but the value of the current through them is not the same.

If the pressures produced by two batteries connected in parallel are equal but their internal resistances are unequal, they will not each carry the same value of current, but the one of lower internal resistance always will carry the larger part of the total current. The reason for this is that the terminal voltages of the two batteries always are equal when the two batteries are connected in parallel, and, in order that this be the case when there is a current through them and their total pressures are equal, it is necessary that the battery of lower internal resistance carry a larger current than the one of higher internal resistance so that their internal drops will be equal.

The above relations readily account for the fact that two batteries will not always operate satisfactorily in parallel as it is really necessary that they have the same internal resistances and produce the same pressures in order that they divide the total current equally for all values of the current they may have to supply. The same thing is true of dry cells.

CHAPTER IV

Making Electricity Do Work

Force

IN general terms, a force is that which produces, stops, changes, or tends to produce, stop, or change the motion or rest of a body. Thus, a force always must be applied to a body to cause it to move, as when you push on a car, and a force must be applied in order to increase or decrease the velocity of a body that is in motion. A force does not always produce motion, but may only tend to produce it, as when you push on a brick wall you apply a muscular force, but there is not necessarily any movement of the wall.

There are a number of different kinds of force, some of the most common of which are as follows: gravitational force, as a result of which all bodies fall from a higher to a lower level; mechanical force, which may be produced by the explosion of a gas mixture in the cylinder of the gas engine; electrical force, which produces or tends to produce a movement of electricity in the electrical circuit; etc. The electrical force is commonly produced by chemical action in the battery or by means of an electrical generator.

An electrical force is measured in volts, while other forces are usually measured in pounds.

Work

If a force overcomes a certain resistance, work is done; or work is the result of the action of a force through a certain distance. Work is measured in a unit which is a combination of the unit in which the force is measured and the unit in which the distance is measured. For example, if you push on a car with a force of 75 pounds and the car moves through a distance of 200 feet, as shown in Fig. 33, the work done will be equal to the product of the value of the force and the distance through which the force acts, or $75 \times 200 = 15{,}000$ foot-pounds.

It must be clearly understood that a force may exist without work being done, as, when you shove on a wall, you do no work unless there is an actual movement as a result of the force.

If a man carries 100 pounds of material from one floor of a building to another floor which is 50 feet above the one from which he started, he will do 100 times 50 or 5,000 foot-pounds of work.

A man would do the same amount of work in carrying 200 pounds of material up a height of 25 feet, 50 pounds up a height of 100 feet, etc.

If a pump raises 1,200 gallons of water a vertical height of 100 feet and each gallon weighs 8⅓ pounds, the work done by the pump will be equal to the weight of the water raised, multiplied by the distance through which it is raised. The weight of the water raised in this particular case is equal to 1,200 × 8⅓ = 10,000 pounds, and since this weight of water is raised 100 feet, the work done will be equal to 10,000 × 100 = 1,000,000 foot-pounds.

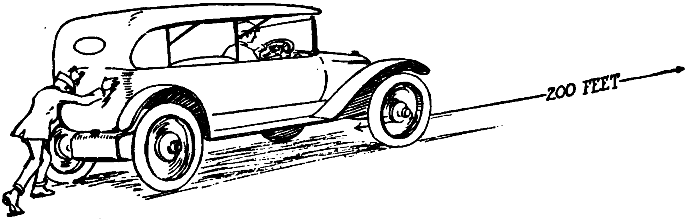


Fig. 33—*Force overcoming distance. If the car is pushed by a force of* 75 *pounds a distance of* 200 *feet the work done will equal* 15,000 *foot-pounds*

The same amount of work would be done in raising 600 gallons to a height of 200 feet, 2,400 gallons to a height of 50 feet, etc.

A motor car weighing 5,000 pounds is to be raised from the ground floor of a building by means of a freight elevator, as shown in Fig. 34, to one of the upper floors which is 50 feet above the ground floor. Assuming that the elevator is properly counterbalanced, and neglecting the friction of the guides, pulleys, ropes, etc., what will be the value of the work done in raising the car to the upper floor? The actual work done in raising the car is equal to the weight of the car multiplied by the distance through which it is raised, namely 5,000 × 50 = 250,000 foot-pounds.

The same amount of work would be done in raising a car weigh-to a point of lower electrical pressure, or it is running down hill electrically.

The same amount of work would be done in operating the motor for 4 minutes if it took a current of 75 amperes, in operating it for 1 minute if it took a current of 300 amperes, etc.

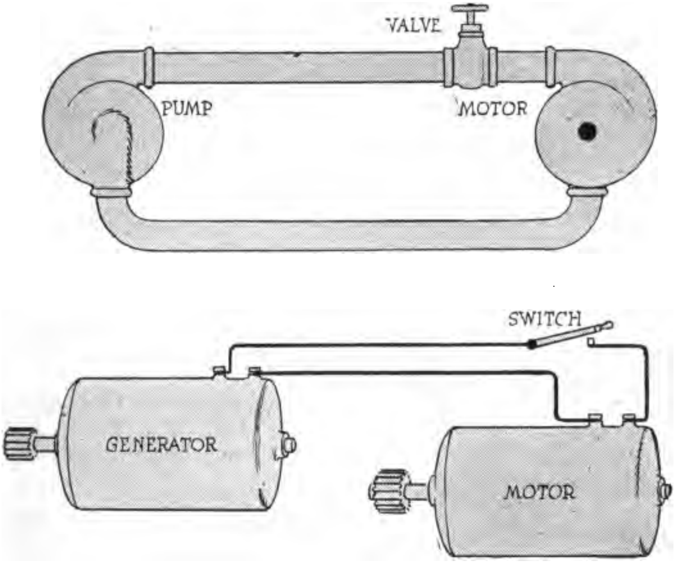
Energy

Energy may be defined as the ability to do work. Thus the energy of a certain quantity of water standing in a pool in the street is zero with respect to the street level as it is not capable of operating a water wheel or any other device when such a device is on the same level as the water. If the water contained in this pool be raised to the roof of a building, the water then possesses some energy with respect to the level of the street and is capable of operating a water wheel or any other device when such a device is on the street level, or located at any point below the level of the water. The energy possessed by the water with reference to the street level when it is raised to the top of the building is equal to the work done in raising the water from the street level to the top of the building.

For example, when 1,200 gallons of water is raised to the top of a building which is 100 feet above the level of the street, the work done, we found in the previous section, was 1,000,000 foot-pounds. The energy possessed by this water then is 1,000,000 foot-pounds and it will do that amount of work if allowed to fall to the street level 100 feet below. You can think of work as being the expenditure of energy and energy, of course, is the ability to do work. The energy possessed by 600 gallons of water which has been raised a vertical height of 200 feet, 2,400 gallons of water which has been raised 50 feet, etc., is the same as the energy possessed by the 1,200 gallons which has been raised 100 feet.

In the case of the car, the work done in raising it a vertical height of 50 feet was 250,000 foot-pounds, and the energy of the car when it is on the upper floor, 50 feet above the ground floor, is 250,000 foot-pounds with respect to the ground floor. If the car be placed on the elevator and allowed to descend to the ground floor it may be made to do just as much work, such as lifting the counterweight, as was done upon it in raising it to the upper floor, neglecting losses of all kinds.

The work done in drawing the disabled car we found to be 1,056,000 foot-pounds, but the energy possessed by the car at the end of the journey was no different from what it was at the beginning, because the car was drawn along a level path. All of the work done on the car is used in overcoming the friction of the various parts. As a result, no energy is stored, as in the case of the water which was raised to the top of the building and the car which was raised in the elevator. If the car had been drawn up a grade instead of along a level path, all of the work done on the car would not be used in overcoming the friction of the various parts but a part would be used in raising the car as it proceeds up the grade.



Figs. 36 and 37—Comparing the closed water circuit and the electrical circuit

The part of the work done in raising the car will represent the difference in the energy stored in the car in the final position and first position. The energy stored in the car when it is raised in passing along the road assists the movement of the car in passing down a grade to the same level from which it started. If no energy be lost in applying the brakes and the car starts and ends at the same level, the same amount of work will be done in moving it along a level road as is done in moving it along an up and down road, as the energy stored in the car as it goes up hill will be used when it goes down grade.

The energy of a certain quantity of electricity at a given point in an electrical circuit with respect to a second point in an electrical circuit is equal to the work done in raising the quantity of electricity from the second point to the first. Thus, in the case of the storage battery, as given in the previous section, the work done was 100,800 joules and this represents the energy stored in the battery, assuming that all of the work done is used in producing a reverse chemical action in the battery. As a matter of fact the work done in charging the battery will be greater than the energy stored in the battery as some work done will be used in overcoming the internal resistance of the battery.

The work in operating the starting motor will be transformed into mechanical work and may turn the engine, or do other kinds of work. If the motor turns the engine there will be no energy stored, but if it raises a weight part of the work it does will overcome the friction of the mechanism it is driving and part of the work will be used in raising the weight.

The work done in raising the weight will represent the value of the energy possessed by the weight in its second position with respect to its first position. This stored energy may be used in doing work.

Comparison of the Water and Electrical Circuits

A comparison of the operation of the closed water circuit, shown in Fig. 36, and the electrical circuit, shown in Fig. 37, will be of interest inasmuch as they are quite similar.

The water circuit consists of a pump connected in series with a water motor by means of several pipes and the circuit is controlled by the valve. The pipes, pump and motor are supposed to be filled with water and when the valve is open there is a flow of water in the circuit, just as much water returns to the pump as leaves it, just as much water leaves the motor as enters it; in fact, the current of water is exactly the same at every point in the circuit at any instant. Remember, the water is not used up.

The electrical circuit consists of a generator connected in series with an electric motor by means of several wires and the circuit is controlled by means of the switch. The generator does not create electricity but merely produces the pressure which tends to cause the electricity to move through the circuit. The same quantity of electricity leaves the generator as enters it, the same quantity of electricity leaves the motor as enters it, in fact, the current of electricity is exactly the same at every point in the circuit at any instant. *Remember, the electricity is not used up.*

If the water is not used up in the water motor and the electricity is not used up in the electric motor, what is it then that causes the water and electric motors to operate in their respective circuits? The pump causes the water to flow from a point of low pressure to a point of high pressure as the water passes through the pump and, in so doing, imparts energy to the water. The energy possessed by the water as it leaves the pump is greater than the energy it possesses when it enters the pump and, as a result, the water is capable of doing work as it passes through the circuit outside the pump. This energy or ability to do work possessed by the water is used in causing the water to flow through the pipes and in operating the water motor.

The generator in the electrical circuit causes the electricity to pass through the generator from the terminal of lower electrical pressure to the terminal of higher electrical pressure and in so doing imparts energy to the electricity. The energy possessed by the electricity as it leaves the generator is greater than the energy it possesses when it enters the generator and, as a result, the electricity is capable of doing work as it passes around the outside circuit. This energy or ability to do work possessed by the electricity is used in causing the electricity to flow through the wires and in operating the electric motor.

High- and Low-Pressure Circuits

The pressure produced by the pump in Fig. 36 may be high, low or what might be called a medium value. If the pressure is low, a relatively large quantity of water must pass through the pipes in a given time in order to operate the water motor; while, if the pressure is high, the quantity of water that must pass through the pipes in a given time is relatively small. The energy possessed by the water when it is acting under a high pressure is greater than when it is acting under a low pressure and hence a certain quantity of water in a high-pressure system is capable of doing more work than a like quantity in a low-pressure system. The current in the high-pressure circuit will be less than the current in the low-pressure circuit.

A similar relation exists in the electrical circuit between the quantity and pressure. That is, the higher the pressure the less the quantity of electricity required to do a certain amount of work and the lower the pressure, the larger the quantity to do the same amount of work. Since there is a smaller quantity of electricity required in the high-pressure circuit than in the low-pressure circuit in order to do a certain amount of work, and assuming the length of time required to do this work is the same in both cases, it is obvious that the current of electricity in the high-pressure circuit will be less than the current of electricity in the low-pressure circuit, just as the current of water in the high-pressure water circuit will be less than the current of water in the low-pressure water circuit.

The high-pressure electrical circuit must be insulated or better protected electrically than the low-pressure electrical circuit, just as the walls of the pipes in the high-pressure water circuit must be stronger than the walls of the pipes in the low-pressure water circuit.

Conservation of Energy

The amount of energy in the universe is always the same, but it assumes many different forms and it is possible for us to transform certain kinds of energy into other kinds of energy. A good example of the transforming process is found in the operation of the steam engine and generator. We start with the energy stored in the coal or other fuel and a part of this energy is used in heating the water in the boiler and thus producing a steam pressure. A part of the energy possessed by the steam is transformed into mechanical energy in the engine which drives the generator. In the generator, a part of the mechanical energy used in driving it is transformed into electrical energy.

The electrical energy produced by the generator may be used in charging a storage battery where a part of it will be transformed into chemical energy; it may be used in operating an electric heater where a part of the electrical energy is transformed into heat energy; it may be used in operating an electric motor where a part of the electrical energy is transformed into mechanical energy and may be used in driving a pump, starting the gasoline engine, operating a fan, etc.; it may be used in operating an incandescent or arc lamp where a part of it is transformed into radiant or light energy, etc.

In the operating of the gas engine, we start with the energy stored in the fuel which may be a gas or liquid and a part of this energy is transformed into mechanical energy which may be used in driving the motor car, the charging generator, circulating pump, etc. You see numerous examples every day in which these or other transformations of energy are taking place.

The all-important point to remember is that *we are not creating or destroying energy but merely transforming it from one kind to another which will better serve our purpose.*

In general, there are two kinds of energy and these are called *potential* and *kinetic* energy, respectively. Potential energy is the energy due to position or condition as, for example, the energy possessed by a certain quantity of water with respect to the ground level when the water is located on a level above the ground; the energy possessed by the volume of water held behind the dam above the water wheel; the energy possessed by a steel spring after it has been put under a strain, perhaps elongated, compressed, or bent out of shape; the energy possessed by a quantity of air stored in a pressure tank; or a pneumatic tire, etc.; the energy stored in the primary or secondary battery; the energy stored in the coal, gasoline, gas, wood, etc., and numerous other examples.

Kinetic energy is the energy of a body due to its motion as, for example, a car in motion; the energy stored in a fly wheel when it is turning; the energy stored in a stone or other body when it is falling, etc.

In throwing a baseball up in the air, the following transformations take place. We start with potential energy stored in the individual who is going to throw the ball, and a part of this energy is imparted to the ball and it is in the form of kinetic energy as the ball leaves the pitcher's hand. This kinetic energy is transformed into potential energy as the ball goes up into the air and finally it possesses no kinetic energy just at the instant it is neither going up or down. The potential energy is then transformed into kinetic energy as the ball descends and the greater part of this kinetic energy will be transformed into heat energy when the ball strikes in the glove or hands of the catcher.

In the various transformations of energy from one kind to another, the transformation is not altogether complete; that is, it never is 100 per cent efficient. Some of it always will be transformed into some other form which we do not want, usually heat. For example, the electrical energy from a battery which is con-

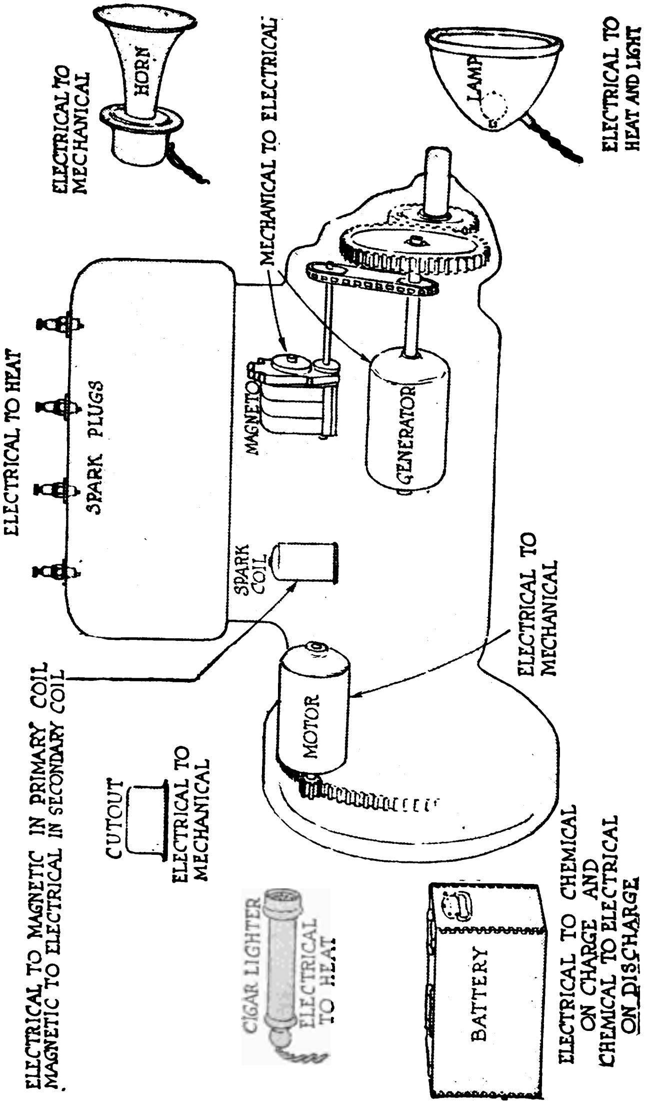


Fig. 38—Transformation of energy in a motor car

nected to a starting motor is not all transformed into mechanical energy, as a part of the output of the battery will be used in causing the electricity to flow through the resistance of the various parts of the circuit. This energy will manifest itself by heating the circuit; that is, it will appear as heat energy. All of the mechanical energy generated in the electric motor is not available to turn the engine crankshaft in starting as a part of the generated mechanical energy must be used in overcoming the friction of the bearing of the motor, the friction of the brushes on the commutator, the fan-like action of the armature as it revolves, which is called windage, and certain other losses which tend to prevent the armature turning.

Returning to the more important electrical circuits or circles of the motor car, we find the following transformations taking place as shown in Fig. 38. Mechanical energy is transformed into electrical energy in the generator and the magneto. Electrical energy is transformed into heat energy in the spark plug, the electric lamp, the electric heater, the cigar lighter, and in the various conductors carrying a current. Electrical energy is transformed into mechanical energy in the electric motor. Electrical energy is transformed into chemical energy in the storage battery when the battery is being charged, and the chemical energy in the battery is transformed into electrical energy when the battery is discharging.

Electrical energy is transformed in magnetic energy in the induction coil as it passes from the primary circuit into the magnetic field of the coil and this magnetic energy is transformed into electrical energy as the energy passes from the magnetic field into the secondary circuit. Electrical energy is transformed into magnetic energy and this magnetic energy into mechanical energy in the various solenoids with a movable armature or core as found in the cutouts, electric gearshifts, etc.

It is desirable to have these various transformations take place as efficiently as possible. For example, a generator which gives out nearly as much electrical energy as it received mechanical energy is more desirable than a generator in which the output and input are widely different. Likewise, a battery whose electrical output after being charged is 80 per cent of its input on charge is a more desirable type, all other conditions being equal, than a battery whose output on discharge is 50 per cent of its input on charge.

CHAPTER V

Electrical Power

POWER is the *rate* of doing work, that is, it is the work done in a given time divided by the time. When the rate of doing work is 33,000 foot-pounds per minute the power is equal to 1 horsepower. This rate of 33,000 foot-pounds per minute is the same as 550 foot-pounds per second, hence, if the rate of doing work is 550 foot-pounds per second, the power is equal to 1 horsepower.

In the preceding chapter, we found that there was 5,000 foot-pounds of work done in raising 100 pounds of material from one floor of a building to another floor 50 feet above the first. The work done is independent of the time but *the power required is dependent upon the time it takes to do the work.* Thus, if it takes 10 seconds for the hoisting machine to raise the 100 pounds 50 feet, the work done per second will be equal to 5,000 ÷ 10, or 500 foot-pounds per second. Now, since 1 horsepower is 550 foot-pounds per second, the horsepower in this particular case will be equal to 500 ÷ 550 or 10/11 horsepower.

The work done in raising the 1,200 gallons of water a vertical height of 100 feet was found to be equal to 1,000,000 foot-pounds. Now, if this operation is to be performed in 1 hour, the rate of doing work per minute will be equal to the total work done divided by the time in minutes, or 1,000,000 ÷ 60, which is equal to 16,666.6 foot-pounds per minute. The power the pump is developing in order to raise this quantity of water will be equal to 16,666.6 ÷ 33,000, or .505 + horsepower. This is the power actually required to lift the water and does not take into account any power lost in the resistance of the pipe due to bends, etc. The power required to drive the pump will be greater than the power the pump develops, as part of the power is lost within the pump itself; hence, the horsepower of an electric motor which may be used in operating this pump must be quite a bit greater than .505 horsepower.

Let us suppose that this quantity of water is to be raised in 2 minutes instead of 1 hour, what horsepower will be required? Remember the work done will be exactly the same but the power must be greater as the same work is to be done in a less time in this case than in the previous case. The rate of doing work in this case is equal to 1,000,000 ÷ 2, or 500,000 foot-pounds per minute. This rate of doing work divided by 33,000 gives the horsepower, which will be equal to 15.15 horsepower. It is obvious that the value of the horsepower required to perform a certain operation will increase as the time of doing the work decreases.

The work done in raising a car weighing 5,000 pounds a vertical height of 50 feet we found to be equal to 250,000 foot-pounds. If this operation is to be performed in 2 minutes, the rate of doing work will be equal to 250,000 ÷ 2, or 125,000 foot-pounds per minute. The horsepower required will be equal to 125,000 ÷ 33,000, or 3.78 horsepower. This is the horsepower actually required to raise the car and does not take into account any power required to take care of the friction of the elevating device. If the car were to be raised in 30 seconds or ½ minute, the rate of doing work would be equal to 125,000 ÷ ½, or 250,000 foot-pounds per minute. The horsepower in this case then is equal to 250,000 ÷ 33,000, or 7.57 horsepower.

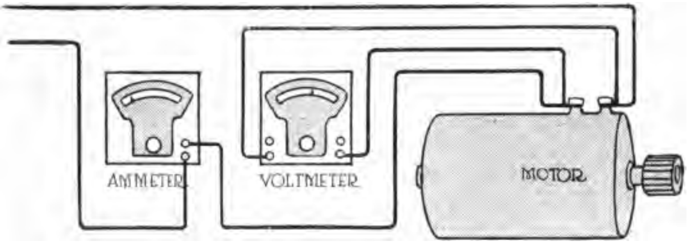


Fig. 39—Measuring power taken by a motor by means of an ammeter and a voltmeter

The work done in drawing the disabled car along the street, we found to be equal to 1,056,000 foot-pounds when the pull in the tow rope was 100 pounds and the car was pulled a distance of 2 miles. Let us suppose this operation is performed in 15 minutes. The rate of doing work will be equal to 1,056,000 ÷ 15, or 70,400 foot-pounds per minute. The horsepower is equal to 70,400 ÷ 33,000, or 2.13 horsepower.

Electrical power is the rate of doing electrical work, that is, it is the electrical work done in a given time divided by the time.

When the rate of doing electrical work is equal to 1 joule per second the power is equal to one *watt.*

The work done in charging a certain storage battery we found to be equal to 100,800 joules. The time required to do this amount of work in this particular case was 1 hour, or 3,600 seconds; hence the rate of doing work was 100,800 ÷ 3,600, or 28 watts.

The work done in operating a certain starting motor we found to be equal to 126,000 joules. The time required to do this amount of work was 2 minutes or 120 seconds and the power is equal to 126,000 ÷ 120, or 1,050 watts.

The power in any part of an electrical circuit may be determined by a more direct method than the one given above and this method may be developed as follows: In determining the work done we multiplied the current by the time in seconds in order to obtain the quantity of electricity passing through the circuit and this result was then multiplied by the value of the difference in electrical pressure or electrical level through which this quantity of electricity moved. This result may all be condensed to the following simple statement:

> Electrical work in joules = current in amperes multiplied by time in seconds multiplied by difference in electrical pressure in volts

$$\text{joules} = \text{amperes} \times \text{seconds} \times \text{volts}$$

The electrical power is equal to the electrical work divided by the time in seconds required to do the work. Hence, if the above expression for electrical work be divided by the time in seconds, we have the value of the power equal to the current in amperes, times the difference in electrical pressure in volts, or

$$\text{Watts} = \text{amperes} \times \text{volts}$$

The power required to charge the storage battery referred to above, then is equal to 4 × 7, or 28 watts. Likewise the power required to operate the motor is equal to 150 × 7, or 1,050 watts.

Measurement of Electrical Power

The power in an electrical circuit or any part of the circuit at any instant is equal to the product of the current in the circuit and the electrical pressure acting on the entire circuit or the part of the circuit in which it is desired to determine the power. For example, the current taken by a motor may be determined by connecting an ammeter in series with the motor as shown in Fig. 39, and the electrical pressure between the terminals of the motor may be determined by means of a voltmeter connected directly to the terminals. The product of the current, as indicated by the ammeter, and the pressure, as indicated by the voltmeter, will give the power taken by the motor.

The above method of measuring power is known as the voltmeter-ammeter method and it gives the value of the power when the circuit is carrying a direct current but does not necessarily do so when the circuit is carrying an alternating current as will be explained in the section dealing with the "Alternating-Current Circuit."

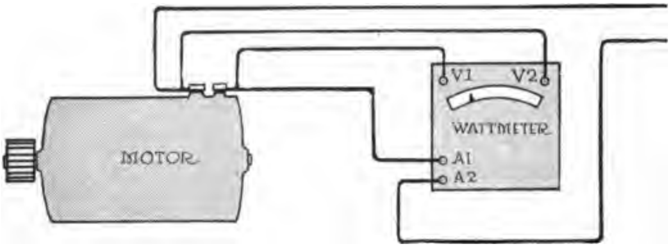


Fig. 40—Measuring power taken by a motor by means of a wattmeter

The power in a circuit carrying either direct or alternating current may be measured directly by means of an instrument called the wattmeter. The construction of this instrument is such that it combines the ammeter and voltmeter in one instrument and the indication of the power is direct without having to multiply current and voltage. The general scheme of connections of the wattmeter is shown in Fig. 40, in which the terminals A_1 and A_2 correspond to the ammeter connections and the terminals V_1 and V_2 correspond to the voltmeter connections.

Relation Between Mechanical and Electrical Power

The relation between the electrical power in watts and the mechanical horsepower has been determined experimentally and the results show that there are 746 watts in 1 horsepower. For example, if a generator is delivering a current of 15 amperes at a pressure of 7 volts, the power in watts will be equal to the product of the current in amperes and the pressure in volts, or

$$\text{Power in watts} = 15 \times 7 = 105 \text{ watts}$$

The power in horsepower will be equal to the power in watts ÷ 746, or

Horsepower = 105 ÷ 746 = .14 horsepower or about 1/7

The maximum current that a certain storage battery can safely deliver is 70 amperes and when this current is being taken from the battery the pressure between its terminals is 7 volts. What is the power output of the battery in watts and horsepower?

Power in watts = 70 × 75 = 525
Horsepower = 525 ÷ 746 = .703

A generator delivers a maximum current of 20 amperes at a pressure of 12 volts and it has an efficiency of 80 per cent for this particular load. What horsepower will be required to operate this generator?

The output of the generator = 20 × 12 = 240 watts.

The statement that the generator has an efficiency of 60 per cent means that 60/100, or 3/5 of the power required to drive the generator, is in turn delivered by the generator to the circuit in which it is connected. The power delivered by the generator, or 240 watts, represents 3/5 of the power required to operate the generator. One-fifth of the power required to operate the generator will be equal to 240 ÷ 3, or 80 watts, and five fifths, or the entire power required to operate the generator, will be equal to 5 × 80, or 400 watts. This power in watts divided by 746 gives the horsepower required to operate the generator, or

Horsepower = 400 ÷ 746 = .53 horsepower

Since power is the rate of doing work, or the rate of the expenditure of energy, that is, it is equal to work done or the energy expended divided by the time, we can say that the energy is equal to the power multiplied by the time. There are a large number of different units for work or energy and some of the more common ones are as follows:

1 horsepower acting for 1 hour is called a horsepower-hour
1 watt acting for 1 second is called a watt-second
1,000 watts, or 1 kilowatt, acting for 1 hour is called a kilowatt-hour.

For example, if a generator requires 10 horsepower to operate it, what energy will be required to operate the generator for 5 hours. The energy in horsepower-hours will be equal to the product of the power in horsepower and the time in hours which is equal to 10 times 5, or 50 horsepower-hours.

If a starting motor takes a current of 100 amperes at a pressure of 6 volts, what energy in kilowatt-hours will be required to operate the motor for 2 hours? The power will be equal to

$$100 \times 6 = 600 \text{ watts,}$$

and the energy will be equal to $600 \times 2 = 1{,}200$ watt-hours.

One kilowatt-hour is equal to 1,000 watt-hours, so to change a given number of watt-hours to kilowatt-hours, divide by 1,000. Then 1,200 watt-hours is equal to

$$1{,}200 \div 1{,}000 = 1.2 \text{ kilowatt-hours.}$$

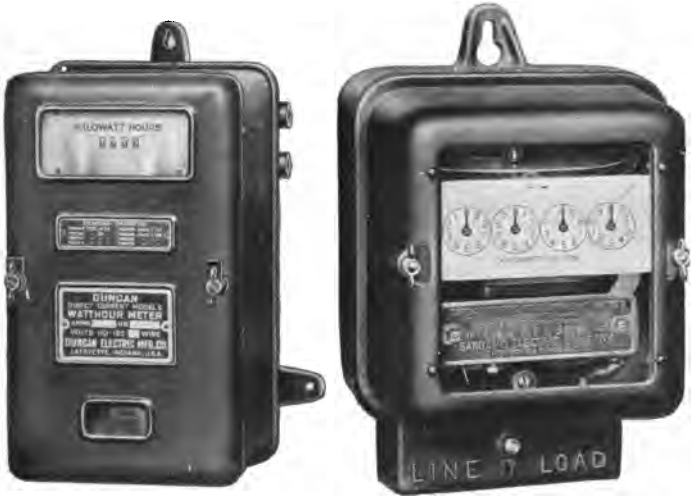


Fig. 41—Two typical forms of watt-hour meters

Measurement of Electrical Energy

The electrical energy required to operate motors, lamps, heaters, etc., may be determined by multiplying the power by the time, provided the power remains constant throughout the entire time. This method of determining the value of the energy cannot be used, however, when the power in the circuit is fluctuating in value as in the case of a motor which is driving a variable load, such as would be found in the ordinary machine shop or in an electric car. The energy in such a case can be determined by means of a watt-hour meter whose dial reading is proportional to the energy that passes through the circuit in which the meter is connected. Watt-hour meters are used by the electrical power companies in measuring energy supplied to their customers and the difference in the readings on the dials of these meters at certain intervals represents the energy used during the period between the times when the meter dials were read. Watt-hour meters are of numerous forms but they all measure energy. Remember that you do not buy electrical *power*, but electrical *energy*, and you usually pay a certain amount per kilowatt-hour.

Two typical forms of watt-hour meters are shown in Fig. 41.

How to Determine the Cost of Charging Storage Batteries

Let us assume that a 6-volt storage battery is to be charged at the rate of 5 amperes for 15 hours from a 115-volt circuit and that the average voltage of the battery during the charging operation is 7.0 volts. What will it cost to charge the battery if you have to pay 10 cents a kilowatt-hour for energy?

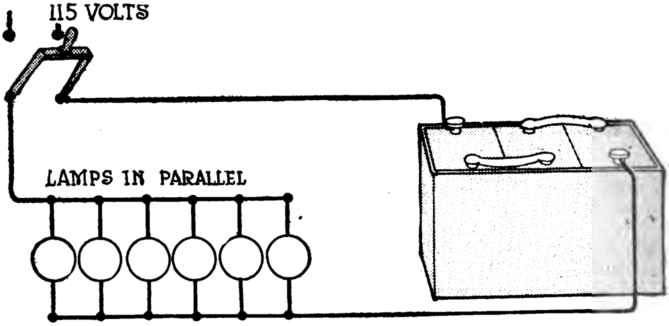


Fig. 42—Showing method of placing lamps in series when charging battery to regulate resistance

It will be necessary to place a bank of lamps or other resistance in series with the battery, as shown in Fig. 42, in order to prevent an excessive current flowing. The pressure acting on the resistance placed in series with the battery will be equal to the difference between the total pressure and the average pressure of the battery which is equal to 115 minus 7, or 108 volts. This pressure of 108 volts is to produce the current of 5 amperes through the series resistance; hence, the value of the resistance will be equal to $108 \div 5 = 21.6$ ohms.

In charging the battery, a large part of the total energy drawn from the circuit will be transformed into heat energy in the charging resistance and lost so far as the battery itself is concerned. The cost of all the energy drawn from the circuit, however, will have to be charged against the battery. The power in the charging circuit will be equal to 115 × 5 = 575 watts.

The energy input to the battery circuit during the 15 hours will be equal to the product of the power in watts and the time in hours which is equal to 575 × 15, or 8,625 watt-hours.

Dividing the value of the energy in watt-hours by 1,000 gives 8.625 kilowatt-hours.

The cost of the energy will be equal to 8.625 × $.10 = $.86. It is readily seen that the cost of charging a battery in the manner indicated above is almost prohibitive and it is due to the simple fact that such a large part of the total energy drawn from the charging circuit is used in the series resistance that had to be inserted in the circuit. Methods of calculating the number and arrangement of lamp to use as resistance for battery charging will be given later.

If a number of batteries be connected in series and all be charged at the same time, the loss in the series resistance will be greatly reduced and the cost of the energy for each battery will be less than in the case of a single battery being charged alone.

For example, suppose fifteen 6-volt batteries be connected in series and charged at a 5-ampere rate for 15 hours from a 115-volt circuit and that the average voltage of each battery during the charging operation is 7.0 volts. What will it cost per battery if you have to pay 10 cents per kilowatt-hour for energy?

The total voltage over the fifteen batteries in series will be equal to 15 × 7 = 105 volts,

and the pressure acting on the resistance placed in series with the battery will be equal to 115 — 105 = 10 volts.

This pressure of 10 volts is to produce a current of 5 amperes, hence the value of the resistance of the series resistance will be equal to 10 ÷ 5 = 2 ohms.

The loss in this 2-ohm resistance will be less than 1/10 of the loss in the 21.6-ohm resistance, assuming they both carry the same current.

The total energy drawn from the circuit will be the same in this case as it was in the previous case, since the value of the current, the pressure and the time are each the same. The cost of the energy in this case, however, is not charged up to a single battery but to fifteen, which greatly reduces the cost of charging a single battery as compared to the case when a single battery was charged at a time. In this case the cost per battery will be equal to .86 divided by 15, or .057 dollars, or 5.7 cents.

Torque

The torque of an engine, electric motor, etc., is the tendency for the shaft of the engine, electric motor, etc., to turn. For example, if a lever be clamped to the shaft of a motor and a spring balance attached to the outer end of the lever, as indicated in Fig. 43, the torque may be measured by noting the pull in pounds on the spring balance and then multiplying this reading by the distance from the center of the shaft of the motor to the point where the spring balance is attached.

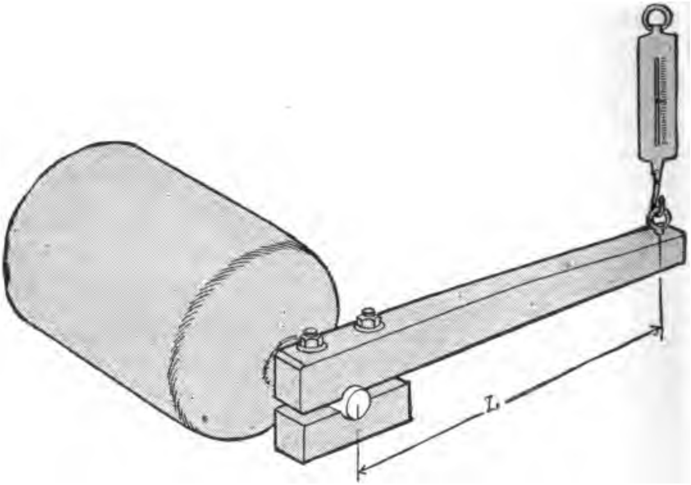


Fig. 43—One of the most simple forms of measuring the torque of a motor

Suppose the conditions are such that the net reading of the spring balance is 10 pounds and that the length L in Fig. 43 is ½ foot. Then the torque is equal to $10 \times \frac{1}{2} = 5$ pound-feet. The unit in which torque is measured is called the pound-foot.

The torque of a revolving shaft may be measured by means of a device called the prony brake, Fig. 43 illustrating one of the simplest forms, though it usually is made to fit a pulley or fly-wheel instead of the shaft itself.

It is interesting to note that the torque is independent of the value of the length L for if this length be increased or decreased there will be a corresponding decrease or increase in the value of the net scale reading, all other conditions remaining constant. For example, if you were holding on to the end of the arm L you would have to exert a greater force with a short arm than with a long arm in order to prevent the arm turning around, but the product of the force and the length of the arm would remain constant so long as the turning effort of the shaft remained constant.

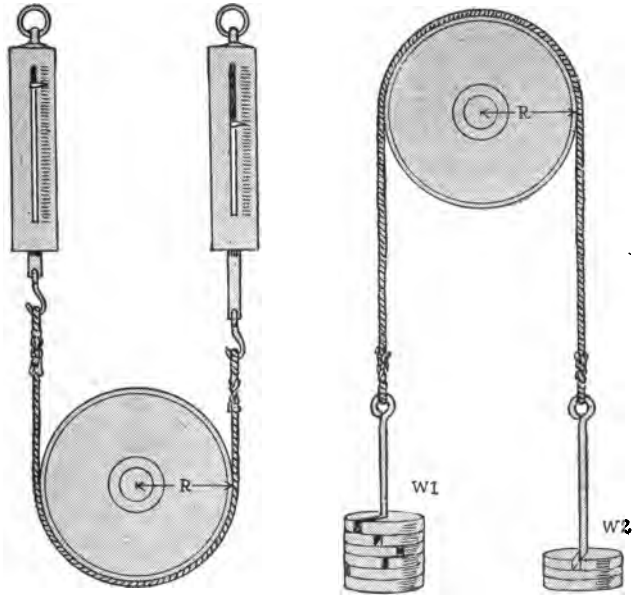


Fig. 44 *and* 45—*Measuring torque by means of two spring balances and also by two sets of weights*

Suppose the prony brake is replaced by a rope as shown in Fig. 44 and that there is a spring balance attached to each end of the rope. The torque in this case is equal to the product of the radius of the pulley in feet and the difference in the readings of the two spring balances. The rope may be placed over the top of the pulley and weights W_1 and W_2 used instead of the spring balances as shown in Fig. 45, and the torque in this case is equal to the product of the radius of the pulley in feet and the difference in the readings of the two spring balances.

In Figs. 44 and 45, there is a force acting at the surface of the pulley which is equal to the difference in the readings of the spring balances or the difference in the two weights in pounds. This force acts through a distance in 1 minute equal to the distance a point on the surface of the pulley travels in 1 minute. If the radius of the pulley in feet be represented by L then a point on the surface of the pulley will travel around the circumference; that is, $2 \times 3.1416L$ or $6,2832 \times L$ feet in each revolution. Now if the number of revolutions per minute be represented by r.p.m., the distance the point on the surface of the pulley travels in 1 minute will be equal to $6.2832 \times L \times \text{r.p.m.}$

This distance, multiplied by the force, which we will represent by W, will give the work done in one minute, or

$$\text{work per minute} = 6.2832 \times L \times \text{r.p.m.} \times W$$

The work done per minute divided by 33,000 will give the horsepower, or

$$\text{horsepower} = \frac{6.2832 \times R \times W \times \text{r.p.m.}}{33,000}$$

In the above expression $R \times W$ represents the value of the torque, hence the equation for horsepower may be written as follows:

$$\text{horsepower} = \frac{6.2832 \times T \times \text{r.p.m.}}{33,000}$$

in which T represents the torque in pound-feet and r.p.m. represents the revolutions per minute.

Determining Torque Starting Motor Must Develop

Since the value of the torque is independent of the lever arm, it makes no difference whether the torque be measured as indicated in Figs. 44 and 45 or by means of the prony brake.

The torque required to turn a gasoline engine over at a given speed may be determined in the following manner: If a wire be wound around the flywheel with one end of the wire fastened to the wheel and the outer or free end attached to a spring balance and a pull then produced on the ring of the balance ample to turn the engine over at the desired speed, the torque required will be equal to the pull in pounds on the wire multiplied by the radius of the pulley in feet. The arrangement of this test is shown in Fig. 46.

The starting motor must be capable of producing the same force at the surface of its pulley or gear when connected as shown in Fig. 46 as is required at the surface of the flywheel to turn the engine over. The torque of the motor, however, will be much less than the torque required to drive the engine, because the radius of the pulley or gear on the motor is much less than the radius of the flywheel. The speed of the motor will be as many times greater than the speed of the engine flywheel as the radius of the flywheel is times the radius of the pulley on the motor. Neglecting losses, the output of the motor in horsepower will be equal to the input to the engine in horsepower, because the product of the speed and the torque in the two cases will be the same.

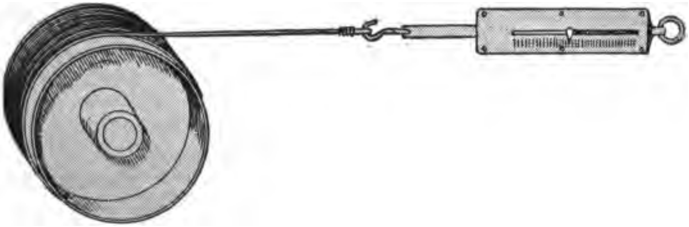


Fig. 46—Determining torque necessary to revolve engine at definite speed

CHAPTER VI

Primary Batteries

Voltage Cell

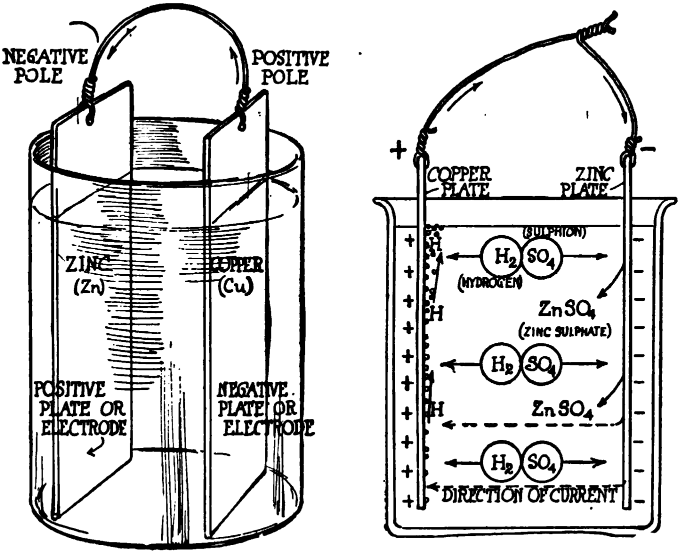
IF two pieces of unlike metals be immersed in a solution, which is capable of acting upon one of them more than upon the other, there will be an electrical pressure set up between them. This electrical pressure will produce a current of electricity between the two pieces of metal when they are connected by a wire which passes from one piece to the other outside the solution. Such a combination of plates and solution constitutes what is called a voltaic cell as it was first discovered by an Italian physicist, Volta, and was named after him. It is, however, sometimes called a galvanic cell, after Galvani, who was Volta's contemporary.

Two pieces of metal, such as copper and zinc, immersed in a solution called the electrolyte of dilute sulphuric acid, as shown in Fig. 47, forms a simple voltaic cell. This cell is capable of producing a continuous flow of electricity through a wire whose ends are connected to the zinc and copper strips. When the electricity flows, the zinc is wasted away, its consumption furnishing the energy required to drive the electricity through the circuit composed of the solution, the two plates and the outside electrical connection between the plates. The cell, for convenience, might be thought of as a chemical furnace in which the fuel is zinc.

The strip of metal from which the electricity flows as it passes through the portion of the circuit outside the cell is called the *positive pole* or *positive terminal* of the cell; while the plate toward which the electricity flows in passing through the portion of the circuit outside of the battery is called the *negative pole* or *negative terminal* of the battery. In the above case, the copper will be the positive terminal and the zinc will be the negative terminal. The positive and negative terminals of a cell are usually designated by the plus (+) and negative (—) signs, respectively.

Primary and Secondary Cells

If a cell is capable of producing an electrical current in a circuit directly from the consumption in it of some substance, such as zinc, it is called a *primary* cell. If, however, a current of electricity must first be sent through the cell to bring it into such a condition that it is capable of producing a current it is called a *secondary*, or *storage* cell. The fundamental distinction, then, between a primary and a secondary, or storage, cell is that, with the latter type the chemical changes are reversible, while with the former type this is not practical, even when possible.



Figs. 47 and 48—Simple voltaic cell made of copper, zinc and sulphuric acid. Fig. 48, at the right, shows the chemical action in the cell

Action of a Primary Cell

The action taking place in the primary and secondary cells, when they are delivering a current, is practically the same but the action in the primary battery is perhaps a little easier followed and it will be given in detail. The cell shown in Fig. 48, which is composed of a piece of zinc and a piece of copper immersed in a solution of dilute sulphic acid, is a good example of a primary cell. Cu is the chemical symbol for copper and Zn for zinc. Water is composed of two parts of hydrogen, whose chemical symbol is H, and one part of oxygen, whose chemical symbol is O, and, accordingly, water is represented chemically by the symbol H_2O.

Sulphuric acid is composed of two parts of hydrogen; one part of sulphur, whose chemical symbol is S; and four parts of oxygen. Accordingly it is represented chemically by the symbol H_2SO_4.

The sulphuric acid acts chemically upon the zinc, the acid is broken up into two parts, H_2 and SO_4. At the same time the chemical action is taking place in the cell, there is a certain amount of electrical activity present. In this particular case, the two parts of the acid, H_2 and SO_4, are charged with positive and negative electricity respectively when they are separated. The SO_4 part possesses a negative charge and hangs on to the zinc plate, giving to the zinc plate a negative charge and at the same time combining with a part of the zinc, Zn.

You can think of the zinc which combines with the SO_4 part of the sulphuric acid as taking the place of the H_2 part of the acid and making a new compound called zinc sulphate and represented chemically by the symbol $ZnSO_4$. This zinc sulphate is dissolved by the water in the cell just as sugar is dissolved when it is placed in water. The result of the action at the negative or zinc plate is a wasting away of the plate itself, the formation of zinc sulphate, and the production of a negative charge on the zinc plate.

The H_2 part of the acid possesses a positive charge and, instead of hanging on to the zinc plate, as in the case of the SO_4 part of the acid, it passes over to the copper plate where it gives up its positive charge and then rises to the surface of the liquid and goes off into the atmosphere. As a result of this action, the positive or copper plate becomes positively charged.

The entire chemical action within the cell is represented by the diagram given in Fig. 48. The acid is broken up into two parts, H_2 and SO_4. The H_2 part has a positive charge of electricity and travels in the direction of the current, and the SO_4 has a negative charge of electricity and it passes in the opposite direction to the current. The fact that the charges of electricity on the two plates are of opposite sign causes a difference in electrical pressure to exist between the two plates. This difference in electrical pressure will produce a current in a conductor connecting the two plates and the chemical action within the cell will continue to go on. The energy of the chemical action within the cell is transformed into the electrical energy of the electricity flowing in the circuit.

If there is no electrical connection between the copper and zinc plate, outside the cell, the chemical action will go on until the two plates are charged, and it then stops.

The action of all primary cells is similar to the one just described. That is, the electrolyte is always broken up into two oppositely charged parts, and these two parts give up their charges to the two plates. The difference in electrical pressure between the two plates depends upon the kind of plates and the composition of the electrolyte, and is independent of the size of the plates or the volume of the electrolyte.

Polarization

The hydrogen gas is likely to cling to the positive plate after it has given up its charge and form a layer of hydrogen gas over the surface of the plate. This accumulation of hydrogen gas in the positive plate is called *polarization*. The hydrogen gas is a very poor conductor of electricity and, as a result, the resistance offered by the cell itself to the flow of electricity through it, which is called the internal resistance of the cell, is increased and a larger part of the electrical pressure between the plates is used within the cell in order to force the electricity through the higher resistance. As a result, there is a decrease in the pressure available outside the cell to force the electricity through the outside circuit.

There is an electrical pressure set up between the film of hydrogen gas and the copper plate whose direction is opposite the electrical pressure between the zinc plate and the copper plate and as a result the net electrical pressure of the cell is decreased.

Depolarization

In order that a cell may operate satisfactorily, it is desirable that the hydrogen gas be removed in some manner from the positive plate, and this process is called *depolarization*. There are various methods employed to depolarize a cell and these methods give rise to the various forms of primary cells.

One of the most common methods is to introduce into the electrolyte some chemical, called a *depolarizer*, which has an excess of oxygen in it. The excess oxygen in the depolarizer readily combines with the hydrogen on the positive plate and forms water, whose chemical symbol is H_2O.

If the action of the depolarizer is rapid, which results in the hydrogen gas being removed as fast as it tends to accumulate on the positive plate, there will be no decrease in the pressure between the two plates of the cell even though it be operated continuously. A cell of this kind is called a *closed-circuit* cell.

If the action of the depolarizer is less rapid and there is a gradual accumulation of hydorgen on the positive plate regardless of the action of the depolarizer, there will be a decrease in the pressure between the two plates of the cell when there is a current through the cell, and as a result the cell may be used only intermittently in order to allow the oxygen in the depolarizer time to clear the hydrogen from the surface of the positive plate. A cell of this kind is called an *open-circuit* cell. The ordinary dry cell is a good example of the open-circuit type of cell, and it is a well known fact that the voltage of a dry cell will decrease when connected to a circuit continuously.

If a closed-circuit cell be allowed to stand on open circuit, that is without there being any outside electrical connection between the plates, the depolarizer in the majority of cases ruins the cell by causing certain chemical changes in the electrolyte. It is essential that the different types of cells be used in the kind of a circuit for which they are intended, in order that the best results may be obtained from the cells.

Local Action

In addition to the polarization action which takes place at the positive plate, there is an action taking place in the cell, usually at the negative plate, called *local action.* This local action is generally caused by some impurity in the material forming the plate. For example, suppose there is a small piece of carbon imbedded in the surface of the zinc but in contact with the electrolyte of dilute sulphuric acid. It is readily seen that a small voltaic cell is formed when the piece of impure zinc alone is placed in the electrolyte as there are two different materials immersed in a solution which acts on one of them more than it does on the other. The acid will be broken up into two parts, H_2 and SO_4, with positive and negative charges respectively. The SO_4 will cling to the zinc and give up its negative charge, and a part of the zinc will combine with the SO_4 to form zinc sulphate, $ZnSO_4$. The hydrogen goes to the piece of carbon and charges it positively, instead of going over to a second or positive plate. As a result of the presence of the impurity in the zinc a small cell is formed and the zinc is consumed but there is not terminal voltage as the carbon and zinc are in direct contact with each other and a short circuit is formed.

Electrochemical Equivalent

The rate at which the negative plate of a voltaic cell is consumed depends upon how much current is passing through the battery. If the plate is pure, there will be no chemical action when there is no current through the cell and hence no metal will be consumed. The rate at which the negative plate is consumed depends upon how much chemical energy must be converted into electrical energy in a given time just as the rate at which coal is consumed in the fire under a boiler depends upon how much heat energy must be transformed into mechanical energy and delivered by the engine. If the cell supplies 1 ampere for 1 hour, there is a definite quantity of zinc consumed, and if it supplies 2 amperes for 1 hour, there is just twice the quantity of zinc consumed. If a current of electricity be sent through a cell in the opposite direction to that in which is tends to flow due to the pressure of the cell itself, there will be a reversed chemical action taking place in the cell and the same amount of zinc will be recovered from the electrolyte and deposited upon the zinc plate in 1 hour by a given current as was consumed in supplying the same value of current for 1 hour. The rate at which the zinc may be recovered from the electrolyte and deposited on the zinc plate will be twice as great for a current of 2 amperes as for a current of 1 ampere; three times as great for a current of 3 amperes as for a current of 1 ampere; etc. This last operation of breaking up the electrolyte and depositing the metal contained in the electrolyte is called *electrolysis.* This is the principle used in electroplating.

The quantity of any metal forming the negative plate of a cell which is consumed in 1 hour, when the cell is supplying a current of 1 ampere, or which is deposited in 1 hour when a current of 1 ampere is caused to flow backward through the cell, is called the *electrochemical equivalent* of the substance.

Damage Due to Electrolysis

Under certain conditions, considerable damage may occur to some part of an electrical circuit due to electrolysis. For example, if two pieces of metal which form a part of an electrical circuit are making poor contact with each other and this contact is moist, there will be a chemical action taking place at the contact when there is a current in the circuit which results in the metal from which the electricity flows being wasted away and carried across the contact and deposited on the other piece of metal.

Polarity Indicator

The positive and negative terminals of a direct-current circuit can be determined by dipping the terminals, at some distance apart, into a tumbler of water. The current in passing through the water decomposes it into oxygen and hydrogen, the oxygen going in the opposite direction to the current and the hydrogen in the same direction as the current. The volume of the hydrogen gas resulting from the decomposition of the water will be approximately twice as great as the volume of the oxygen gas, and hence, there will be more bubbles collected on the negative terminal than on the positive terminal, as shown in Fig. 49.

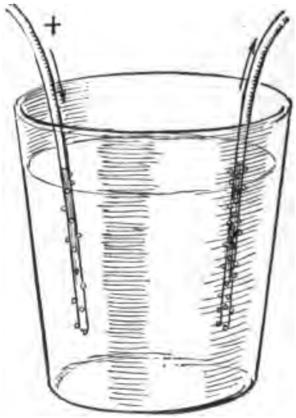
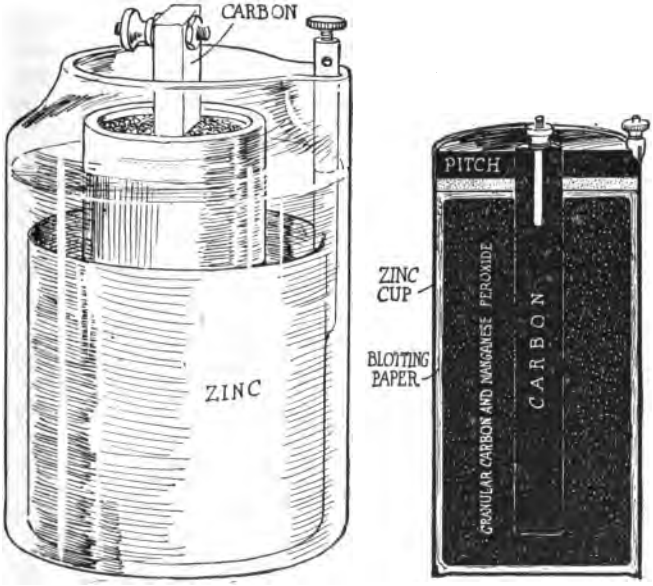


Fig. 49—To tell the positive terminal from the negative terminal of a battery, connect a wire to each pole and dip the ends of the wire in a glass of water. The current decomposes the water into hydrogen and oxygen, the hydrogen coming off the negative pole and the oxygen off the positive terminal. As there is twice as much hydrogen as oxygen in water, the terminal giving off most bubbles is the negative

A solution of iodide of potassium, with a little starch added, is sometimes sealed in a short piece of glass tubing and terminals provided at the ends by which contact can be made with the solution. When a current is produced in the solution, iodine is liberated at the positive terminal and turns the starch blue around this terminal.

The Leclanche Cell

The Leclanche cell is a good example of an open type of wet cell, and its operation will be given somewhat in detail as the operation of the dry cell described in the next section is practically the same. The first forms of this cell consisted of a carbon rod imbedded in a mixture of manganese peroxide, and broken carbon, all contained in a porous cup. This cup was placed in an electrolyte of ammonium chloride commonly called sal ammoniac, and the negative terminal was formed from a piece of sheet zinc but into a cylindrical form and surrounding the porous cup. The construction of the cell is shown in Fig. 50. The manganese peroxide forms the depolarizer and the only object of the porous cup was to hold the mixture of manganese peroxide and broken carbon around the positive plate.



Figs. 50 and 51—Leclanche cell, a typical wet cell, at left, and a common type of dry cell at right

In the more modern forms of this cell, the porous cup has been dispensed with and a mixture of carbon and manganese peroxide are moulded together with a suitable binder.

Dry Cell

The modern dry cell, so extensively used at the present time, may be looked upon as a slight modification of the Leclanche cell. The chief difference between them is that only enough water is added to the material forming the electrolyte to moisten it and an absorbent layer of starch paste, blotting paper, or cloth which separates the positive and negative poles of the cell. The negative pole is a hollow zinc cylinder closed at one end, which also serves as a container for the remainder of the cell. The absorbent layer used to separate the positive and negative poles is saturated with a solution of sal ammoniac and zinc chloride and placed next to the zinc on the inside of the cylinder. The remaining space between the absorbent layer and the carbon rod is filled almost to the top with a moist mixture composed chiefly of manganese peroxide and granulated carbon. The manganese peroxide acts as the depolarizer. The remaining space at the top of the cup is usually filled with a pitch composition which seals the cell. Terminals are provided at the upper end of the piece of carbon and also at the upper edge of the zinc cup. A vertical cross section of a modern dry cell is shown in Fig. 51.

The internal resistance of a good dry cell when new should be less than .1 ohm but may increase to several times this value within 6 months to 1 year even though the cell may not be in use.

The electrical pressure produced within a dry cell, called its electromotive force, should be in the neighborhood of 1.5 to 1.6 volts when the cell is quite new. The pressure between the terminals of the cell, called its *terminal voltage,* is equal to the electromotive force of the cell when there is no current through the cell. The terminal voltage drops when a current is supplied by the cell, due to the internal resistance and polarization of the cell. In the majority of dry cells, the effect of the counter electromotive force due to polarization is greater than the effect of internal resistance and the average terminal voltage of the cell during its useful life is not much greater than 1 volt.

About ninety per cent of the people using dry cells test them by measuring the current they will supply when the terminals of the cell are connected directly to the terminals of a low resistance ammeter. This sort of a test does not take into account such factors as the temperature, the kind of service for which the cell is to be used, etc., and as a result is not altogether reliable. The same cell will produce a different current through ammeters of different resistances due to there being a different resistance in circuit in the two cases. The higher current being produced with the low-resistance ammeter and the smaller current with the high-resistance ammeter. The maximum current output can be obtained when the resistance outside of the cell is equal to the resistance inside of the cell.

The effect of temperature on the current a cell will supply when connected directly to the terminals of an ammeter is quite pronounced. There is a change in the value of the current of about 1 ampere for each 10 degrees centigrade change in temperature for all temperatures ranging in value from 0 to about 90 degrees.

A good dry cell should produce a current, when its terminals are connected directly to an ammeter, of from 16 to 25 amperes with an external resistance not exceeding .01 ohm. A cell producing a current much less than 16 amperes is more than likely composed of cheap materials or it has been made for a long time. If the cell produces a current much in excess of 25 amperes it is likely to polarize rapidly and as a result its terminal voltage will decrease faster than one which produces a lower current.

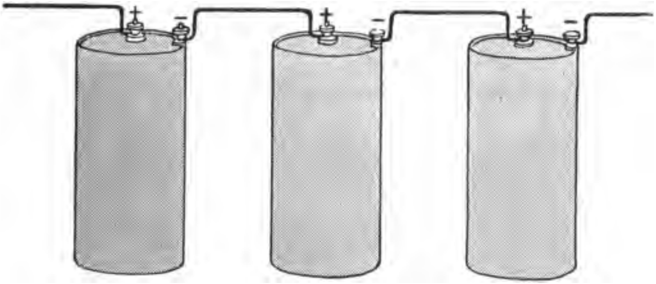


Fig. 52—Three dry cells connected in series, the negative terminal of one cell joined to the positive plate of the next

The ampere-hour capacity of a dry cell ranges in value from 5 to 25 ampere-hours, when discharging continuously through a resistance of 15 ohms until the terminal voltage drops to .5 volt, depending upon the quality of materials used, the age of the cell, the temperature of the cell, etc. The ampere-hour capacity of a dry cell is greater when it is called upon to produce a small current than when it is called upon to produce a relatively large current. Thus a cell producing a current in a circuit of 16 ohms will supply a larger number of ampere-hours than it would if producing a current in a 4-ohm circuit.

The ampere-hour capacity of a battery on intermittent service, such as in ignition, is entirely different from its ampere-hour capacity when producing a current continuously. The terminal voltage will decrease more rapidly at first when the cell is producing a current continuously than when it is producing a current intermittently, but, after the cell has been in service for some time, the terminal voltage of the cell producing the current intermittently will decrease faster than the terminal voltage of the cell producing the current continuously.

An Electric Battery

If a number of cells be connected in series—the negative plate of one cell joined to the positive plate of the next cell, and so on—an electrical pressure will be produced between the positive plate at one end and the negative plate at the other end equal in value to the sum of the pressures produced by the different cells connected in series. Three dry cells are shown connected in series in Fig. 52.

If a number of cells be connected in parallel—the negative plates of all the different cells connected together to form one terminal and the positive plates of all different cells connected together to form a second terminal—an electrical pressure will be produced between the positive terminal and the negative terminal equal in value to the pressure produced by a single cell, provided the different cells are each producing the same pressure. Three cells are shown connected in parallel in Fig. 53.

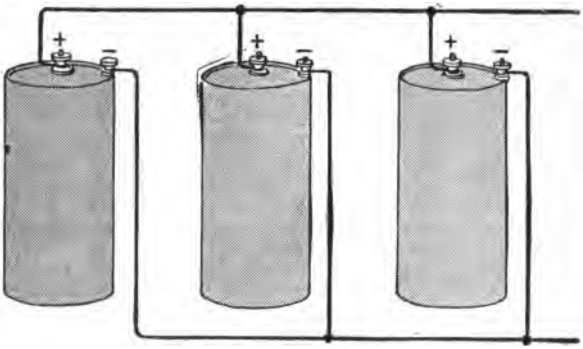


Fig. 53—Three dry cells connected in parallel or multiple, the negative plates of all joined together and the positive plates of all joined

Any series, parallel, or a combination of series and parallel connections of cells constitutes a battery.

It is customary in practice to represent a cell by means of two parallel lines, instead of drawing a picture of the cell each time you want to show it in a diagram. In Fig. 54, a battery of three cells is represented. The long line corresponds to the plus (+), or positive, terminal, and the short line corresponds to the minus (—), or negative, terminal.

Proper Combination of Cells for Best Results

Suppose that a piece of apparatus having a resistance of 16 ohms is to be operated from dry cells and that the voltage must not be less than 2 volts at any time. Two cells connected in series will produce the desired results until their terminal voltage drops to 1 volt per cell. If, however, four cells be used and they be connected two in series and the two series groups in parallel, a much longer life will be obtained from the cells than when only two cells are used.

In the first case, the two cells are each carrying the total current, while in the second case, each cell is carrying only one-half of the total current as there are two groups of cells in parallel. In the second case, each group of cells might be thought of as discharging through a resistance of 32 ohms rather than 16 ohms and the life will be more than twice as great as the life of the two cells when used alone or discharging through a resistance of 16 ohms.

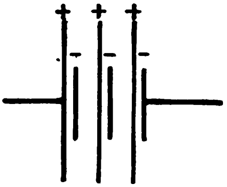


Fig. 54—Usual way of representing a battery in wiring diagrams. The + and — marks usually omitted

When a number of cells are connected in parallel, they should all produce the same electrical pressure and have the same internal resistance. If the electrical pressure in one path of the parallel circuit is greater than the electrical pressure in the other path or paths, then there will be a current through the path of higher pressure into the path or paths of lower pressure. The direction of this current in the path of higher pressure will correspond to the direction of the pressure in that path, while the current in the path or paths of lower pressure will be in the opposite direction to the pressure in the respective paths. This condition of affairs results in the cells in one path discharging into the cells in some other path or paths and there is a chemical action taking place, which is detrimental to the life of the cells, even though there be no current supplied to the device or apparatus the cells are to operate. For this reason it is always advisable to have the total pressure in each path of a parallel circuit, formed by connecting a number of cells, the same.

If the resistance of one path of a parallel circuit, formed by connecting a number of cells in parallel, is greater than the resistance of the other path or paths, then a greater pressure will be required to produce a current of a certain value in this circuit than will be required to produce a current of exactly the same value in the other circuits. The same loss or drop in pressure will be produced by a small current in the path of high resistance and by a larger current in the path of lower resistance. Assuming the total pressures in the different paths are equal, and since the pressure between the terminals of all the paths will be the same, then the drop or loss in pressure in each path will be the same, and hence, it is obvious that the current in each path cannot be of the same value. The path of higher resistance will carry a smaller current than the path or paths of lower resistance. In order that cells may operate satisfactorily in parallel, it is desirable that the total internal resistance and the resistance of the connecting leads be the same in each path.

CHAPTER VII

Storage Batteries

Distinction Between Primary and Storage Batteries

WHEN the negative plate of a primary battery is nearly consumed, it is customary to replace it with a new plate; or, in the case of the dry cell, to replace the entire cell by a new cell. If a current of electricity be sent through the cell from an outside source in a direction opposite to the direction of the pressure produced by the cell and the metal in the electrolyte deposited back on the negative plate, instead of replacing the plate or the entire cell, the cell is called a storage battery. When a current as passing through a storage cell in the direction of the pressure; that is, from the negative to the positive plate within the cell, the cell is said to be discharging; and, when a current is passing through the cell in the opposite direction to its pressure; that is, from the positive to the negative plate within the cell, the cell is said to be charging.

The fundamental principles of the storage battery differ in no way from the primary cell; that is, any primary cell could be used as a storage cell and have its negative plate restored by sending a current through the cell in the opposite direction to its pressure, as is done in the commercial types of storage cells. The ordinary primary cell cannot have its negative plate restored economically and hence it is commercially more efficient either to replace the negative plate by a new one or to replace the entire cell when the negative plate has nearly wasted away. There are, however, some certain combinations of plates and electrolytes which may be used as a storage cell when especially constructed for the purpose.

You must get this fact clearly fixed in your mind—*a storage cell does not store electricity, but it stores chemical energy.*

During the process of charging electrical energy is transformed into chemical energy and stored within the cell; while during the process of discharging, chemical energy is transformed back into electrical energy. Neither of these transformations is made without some loss which prevents as much energy being drawn from the cell when it is discharging as was put into it when it was charging.

Types of Storage Cells

Storage cells may be divided into two main groups, according to the kind of materials used in the construction of the plates. These groups are lead storage cells and non-lead storage cells, and the construction and operation of the two types will be discussed somewhat at length in the following sections. A great deal more attention will be given to the lead storage battery on account of its characteristic at present being such as to make it much better suited to the requirements of the starting and lighting equipment.

Lead Storage Cells

In the construction of the lead storage cell, the *cathode,* or positive plate, **is** composed of lead peroxide, PbO_2; the negative plate, or *anode,* is composed of pure spongy lead, Pb; and the electrolyte is sulphuric acid, H_2SO_4, diluted with water, H_2O.

Spongy lead and lead peroxide are rather poor conductors of electricity and their mechanical characteristics are such that they cannot be made into plates themselves and it is necessary that they be supported by frames of some material which is stronger and harder, and at the same time a better conductor of electricity. The material used for these frames must be one which is not acted upon by the acid, as otherwise there would be a local action between the spongy lead and the frame or between the lead peroxide and frame whenever they happened to be in contact. The material that is most generally used in constructing these frames, usually called grids, is an alloy of lead and antimony, which is mechanically stronger and stiffer than pure lead and it is not acted upon to any great extent by the sulphuric acid.

The lead peroxide and spongy lead are usually spoken of as the *active materials,* in order to distinguish them from the grids. The combination of active material and framework is spoken of as a *plate.* It is a positive plate when it is a combination of lead peroxide and the framework, and negative plate when it is a combination of spongy lead and the framework.

General Types of Lead Cells

There are two general methods of attaching the active material of a plate to the framework and these methods of constructing the plates give rise to two types of lead cells. These two types are known as the Plante and Faure.

The Plante plate is made by taking a sheet of lead and preparing its surface so that a large area is exposed and then oxidizing this surface into lead peroxide by treating the plate chemically or by means of an electric current, thus forming the positive plates. The negative plates are formed by taking the peroxide plates and connecting them as the cathodes with lead sheets as the anodes, in a solution of diluted sulphuric acid, and passing a current from one plate to the other from an outside source. The hydrogen set free from the acid combines with the oxygen of the lead peroxide and reduces the lead peroxide to spongy lead. This process results in a thin layer of active material being formed on the surface of the plate which is quite porous and firmly attached to the grid. The area of the surface of the lead plates may be increased by cutting a large number of narrow grooves in their surface or by corrugating the plates. In one particular type of construction for stationary batteries the area of the plates is increased by forming buttons of narrow strips of corrugated pure lead ribbon and forcing them into circular openings in the framework.

The Plante type of grid is usually used where weight and space are of no great importance and for this reason they are not used to any great extent in motor car work.

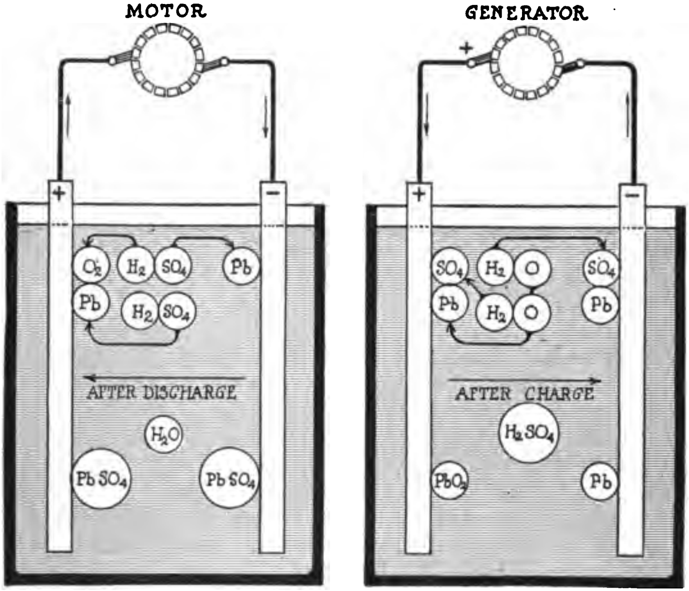
In the Faure plate, the active material, instead of being formed by chemical action or by the action of an electric current, as in the case of the Plante plate, is formed by introducing a paste of active material, formed principally from compounds of lead mixed with a weak solution of sulphuric acid and water, into openings in the grid. The composition of this paste or active material as used by the different companies may be quite different and it is also quite different for different types of cells in order that the finished plate may be made compact, porous and at the same time not readily crumble away. This type of plate is usually spoken of as the pasted plate, and it is used chiefly where it is desired to obtain the greatest possible capacity with a minimum of weight and space occupied. This type of lead plate is used more than any other type in motor car work.

Chemical Action Within a Storage Cell When Discharging

In discharging a storage cell the electrolyte H_2SO_4 is split up by the action of the electric current into hydrogen, H_2, and sulphion, SO_4. The hydrogen, which passes in the direction of the current, is liberated at the cathode and combines with some of the oxygen in the lead peroxide forming water, H_2O, thus converting the lead peroxide into lead oxide, PbO. The lead oxide is supposed to combine immediately with a part of the electrolyte, H_2SO_4, forming lead sulphate, $PbSO_4$, and water, H_2O. Lead sulphate is also formed at the anode by the sulphion, SO_4, combining with the spongy lead, Pb. The cell will continue to deliver current until the plates are entirely reduced to lead sulphate, when all action will cease, as there is but one kind of material in contact with the electrolyte and a cell requires two kinds. In practice, however, the practical limit of discharge is reached before the surfaces of both plates are reduced to the same material.

The lead sulphate which is formed during the process of discharging is more bulky than the active materials themselves, and, as a result, there is an expansion in the surface of the plates of the cell. The lead sulphate has a higher electrical resistance than the active materials, which causes the internal resistance of the cell to increase as the discharge continues. There is also a decrease in the density of the electrolyte as the discharge continues on account of the absorption of the sulphion, SO_4, by the active material.

The chemical action taking place in a lead storage cell when it is discharging is shown diagrammatically in Fig. 55. The direction of the current within the cell is from the negative plate whose active material is spongy lead, Pb, toward the positive plate whose active material is lead peroxide, PO_2. The sulphuric acid in contact with the negative plate is broken up into SO_4 and H_2, and the positively charged hydrogen, H_2, carries its charge over to the lead peroxide plate where it gives it up and combines with the oxygen of the lead peroxide forming water. The SO_4 part of the acid in contact with the negative plate combines with the spongy lead and forms lead sulphate, $PbSO_4$. The acid in contact with the positive plate is also broken up into SO_4 and H_2, and a part of the oxygen in the lead oxide combines with the hydrogen, H_2, forming more water, H_2O. The sulphion, SO_4, instead of going over to the negative plate combines with the lead of the lead peroxide to form lead sulphate, $PbSO_4$.



Figs. 55 and 56—Chemical action in a storage cell during discharge, at left, and during charge, at right

The chemical action may be written in the form of an equation as follows:

Action at positive plate, cell discharging
PbO_2 plus H_2 plus H_2SO_4 produces $PbSO_4$ plus H_2O
Lead peroxide plus hydrogen plus sulphuric acid produces lead sulphate plus water
Action at negative plate, cell discharging
Pb plus SO_4 produces $PbSO_4$
Lead plus sulphion produces lead sulphate

There are two things which are taking place when the cell is discharging. First, the acid is continually growing weaker and second, the active materials, lead peroxide and spongy lead, are being replaced by lead sulphate. This lead sulphate is more bulky than the active materials which it replaces and as a result the pores in the surface of the plates become more or less filled, which to a certain extent prevents the acid and active materials coming into contact with each other.

Chemical Action When Charging

In charging a storage cell, a chemical action takes place which is just the reverse of the chemical action taking place when the cell is discharging. The lead sulphate, $PbSO_4$, on the positive plate is converted back into peroxide of lead, PbO_2; while the lead sulphate on the negative plate is converted back into spongy lead. The density of the electrolyte increases, due to the fact that the SO_4 part of the lead sulphate combines with hydrogen and forms sulphuric acid.

The chemical action taking place in a lead storage cell when it is being charged is shown diagrammatically in Fig. 56. The direction of the current within the cell is from the positive toward the negative plate. Two parts of oxygen combine with the lead part of the lead sulphate in the positive plate and form lead peroxide, PO_2. The SO_4 part of the lead sulphate on the positive plate combines with two parts of hydrogen and form sulphuric acid. Two parts of hydrogen combine with the SO_4 part of the lead sulphate on the negative plate and form sulphuric acid; while the lead part of the lead sulphate on the negative plate remains on the surface of the plate as the active material.

The chemical action may be written in the form of an equation as follows:

Action at positive plate, cell charging

$PbSO_4$ plus H_2O plus O produces PbO_2 plus H_2SO_4

Lead sulphate plus water plus oxygen produces lead peroxide plus sulphuric acid

Action at negative plate, cell charging

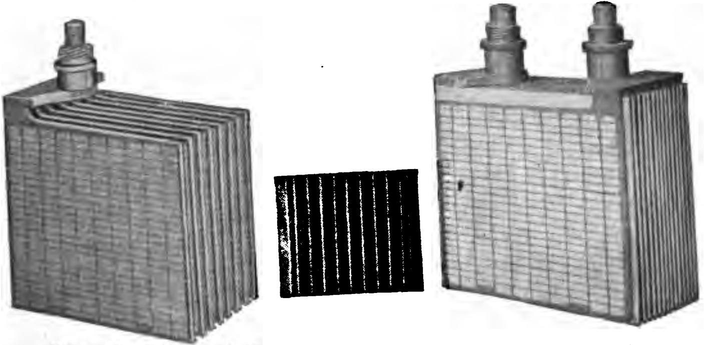
$PbSO_4$ plus H_2 produces Pb plus H_2SO_4

Lead sulphate plus hydrogen produces lead plus sulphuric acid

The changes taking place in a lead storage cell when it is charging result in the lead sulphate on the positive plate being replaced by lead peroxide, the lead sulphate on the negative plate being replaced by pure lead and the electrolyte becoming stronger.

Arrangement of Plates in a Lead Storage Cell

Every storage cell contains two kinds of plates, positive and negative. In some very small cells there are only two plates, one positive and one negative. In the majority of cases, however, there are a number of both positive and negative plates, and they are arranged alternately with respect to each other. All of the positive plates are connected to lead bars which form the positive terminal of the cell, and all of the negative plates are connected to lead bars which form the negative terminal. Since there is a greater chemical action taking place at the surface of the positive plate than is taking place at the surface of the negative plate, it is customary to arrange the plates so that there is a negative plate on both sides of each positive plate, which results in practically the same action taking place on both sides of every positive plate. With this arrangement, there will be required one more negative plate in a cell than there are positive plates.



Figs. 57 and 58—A group of plates for a storage cell, at left; a separator, center, and an element, consisting of a group of positive plates, a group of negative plates and their separators, at right

The plates are prevented from coming into contact with each other by means of what are called *separators,* which are generally made from wood, treated to remove all acids and other injurious matter. Other materials are used in the construction of separators, the principal one of which is rubber, but not to anything like the extent that wood is used. In some makes of cells the plates are held apart by means of special mechanical devices. The separators are made quite thin and they are usually ribbed vertically on one side. The ribbed side is placed next to the positive plate which readily permits the comparatively large amount of active material which is loosened from the surface of the plate during the operation of the cell to fall to the bottom of the cell.

A complete set of positive or negative plates fastened to a bar or strap of lead is called a *group*, and it will be spoken of as a positive or negative group depending upon whether the plates are positive or negative. A group of plates is shown in Fig. 57.

A combination of positive and a negative group of plates together with the separators constitute what is called an *element*. A complete element for a starting and lighting battery is shown in Fig. 58.

Containers for Lead Storage Cells

The container for a storage cell is the vessel containing the electrolyte and into which the element of the cell is placed. The container should always be made from a material that is not acted upon by the electrolyte and its mechanical characteristics should be such that it will withstand the excessive vibration of the motor car and ordinary abuse in handling. Rubber is generally used in the construction of the container for storage cells to be used on motor cars as it readily meets the above requirements.

The container is usually constructed with stiff ribs across the bottom and on the inside which serve to support the element and at the same time provide a space below the element into which any sediment or loose material resulting from the operation of the cell may accumulate.

The containing case is usually provided with a suitable cover which is sealed into position after the element has been put in place by means of some kind of a pitch compound. Special means are employed by the different companies in making a tight seal around the top of the cell and terminals of the groups where they pass through the cover of the cell.

Each cell must be provided with a suitable vent through which the gas formed during the operation of the cell may escape, and through which the electrolyte may be poured into the cell and electrolyte or distilled water added as may be required from time to time.

The various cells forming the storage battery are arranged in a substantial wooden box thoroughly coated with an acid-proof paint and provided with suitable handles for carrying the battery and also for anchoring it in position on the car. In the majority of cases a layer of sealing compound is placed over the entire number of cells after they are all in place in the containing case, while in some makes the sealing of each individual cell is ample to prevent any seeping of the electrolyte out into the wooden box. When the sealing of each cell is entirely separate, it is possible to remove any one of the cells from the battery for inspection or repairs a great deal easier than it is where the entire battery is covered with a layer of sealing compound. The arrangement of the various parts of a complete storage battery is shown in Fig. 59, a part being cut away so as to show the interior.

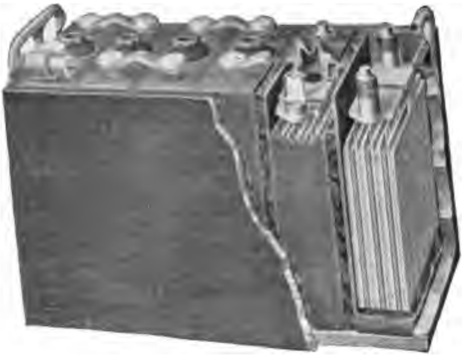


Fig. 59—*A 12-volt storage battery, showing how the cells are arranged and the plates within them*

Electrolyte for Lead Storage Batteries

The electrolyte for lead storage batteries consists of pure sulphuric acid and water. Concentrated sulphuric acid is a heavy, oily liquid having a specific gravity of about 1,835. This acid is diluted with water until its gravity is in the neighborhood of 1,270 to 1,300 for a fully charged battery, as the best results are obtained in the operation of the battery with acid of this gravity.

By the term specific gravity is meant the relative weight of any substance as compared to water. Pure water is taken as a standard and its specific gravity is taken as 1 usually written 1,000 and spoken of as ten hundred. Thus, if you were to weigh a certain volume of water and then weigh an exactly equal volume of some other material, the specific gravity of the material would be equal to weight of the upright position when it is placed in the liquid, and provided with a suitable scale marked on the glass tube or on a piece of paper inside the tube. The depth to which the hydrometer sinks in the liquid, whose specific gravity is being determined, as indicated on the scale of the instrument where the surface of the liquid is in contact with the tube, is a measure of the specific gravity of the liquid. The temperature of the electrolyte may be determined by means of a thermometer and corrections made in the specific gravity as has been explained above.

For convenience in using the hydrometer, it is usually placed inside of a larger glass tube provided with a rubber bulb at one end and a suitable nozzle or short piece of hose at the other. This combination is known as the hydrometer syringe, and is shown complete in Fig. 61. If the bulb be squeezed and the lower end inserted into the electrolyte through the vent opening of the cell, electrolyte will be drawn up into the large glass tube when the bulb is released. It will of course be necessary to draw up sufficient electrolyte to float the hydrometer. The specific gravity should be read at the surface of the electrolyte when the syringe is in a vertical position and there is no pressure on the bulb.

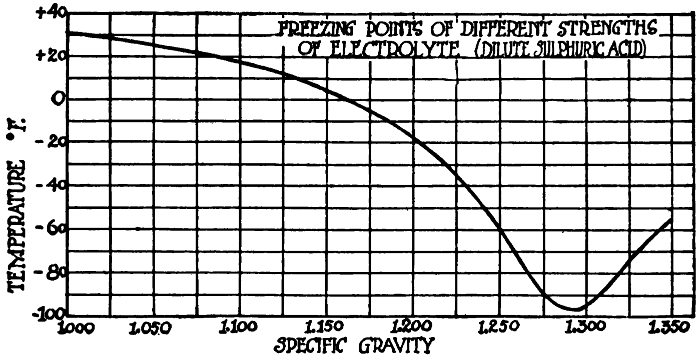


Fig. 62—*Temperature at which electrolyte will freeze. Note that up to a specific gravity of* 1,300, *the greater the specific gravity, the lower the freezing point*

Care should be exercised in returning the electrolyte to the cell to make sure that it is not drawn from one cell and returned to another, which would result in the electrolyte in one cell being weakened as water eventually would be put in to replace the electrolyte, while in the cell to which the electrolyte was transferred there would be an increase in specific gravity.

The temperature at which sulphuric acid freezes depends upon the specific gravity. The relation between the temperature at which the electrolyte will freeze and its specific gravity is shown by means of a curve in Fig. 62. It is readily seen from an inspection of this curve that there is little danger of the electrolyte freezing unless the battery is discharged, in which case the specific gravity will be relatively low.

The specific gravity of the electrolyte in a cell will change when the cell is being charged and discharged, increasing while the cell is being charged and decreasing when the cell is being discharged. This change in the specific gravity of the electrolyte offers quite a reliable means of determining the condition of charge of the cell. Assuming the electrolyte has a specific gravity approximately 1,300 when the cell is fully charged, the specific gravity will drop as indicated in Fig. 63 as the cell discharges.

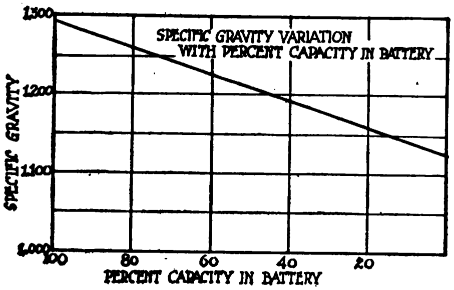


Fig. 63—*How the specific gravity of a cell drops as it is discharged. Note that battery men usually write specific gravity as though it were based on a standard of* 1,000; *thus, full charge* 1,300. *However, the gravity really is based on a standard of* 1; *thus, full charge* 1.300

Ampere-Hour and Watt-Hour Capacity of a Storage Cell

The normal ampere-hour capacity of a storage cell is equal to the quantity of electricity in ampere-hours that the cell will supply when it is discharged at such a constant current that the terminal voltage of the cell will fall to 1.7 volts, in 8 hours. For example, a cell is said to have an ampere-hour capacity of 60 ampere-hours, which means that the cell will supply a current of 7.5 amperes continuously for 8 hours at 70 degrees Fahrenheit without the terminal voltage decreasing below 1.7 volts. The ampere-hour capacity of a battery formed of a number of cells connected in series will be the same as the ampere-hour capacity of a single cell, but the pressure producing the current will be equal to the pressure of a single cell multiplied by the number of cells. If the cells be connected in parallel, the ampere-hour capacity of the battery will be equal to the ampere-hour capacity of a single cell multiplied by the number of cells, but the pressure producing the current will be equal to the pressure of a single cell. The ampere-hour capacity of each cell depends upon the total area of the plates exposed to the action of the electrolyte.

The watt-hour capacity of a storage cell is equal to the ampere-hour capacity multiplied by the average voltage during discharge. The watt-hour capacity of any number of cells connected in parallel or series will be equal to the watt-hour capacity of a single cell multiplied by the number of cells connected in circuit, assuming they are all identical.

The capacity of a given storage cell is not constant but depends upon a number of conditions, such as the temperature of the cell, the rate at which the cell is discharged, the specific gravity of the electrolyte, the attention the cell has received and the kind of service to which it has been subjected.

The higher the rate of discharge, the lower the ampere-hour and watt-hour capacities of the cell and the lower the rate of discharge, the higher the ampere-hour and watt-hour capacities of the cell.

This decrease in capacity due to high rates of discharge is largely due to the fact that the electrolyte has not ample time to penetrate the pores of the active material and as a result, some of the active material is not available. If a cell be discharged at a high rate to the minimum voltage allowed for that rate, and then allowed to stand for some time, it will be capable of delivering an additional quantity. Thus, a storage battery may appear to be completely exhausted when it has been used in operating the starting motor for a considerable time and it will not even operate the lamps at a reasonable voltage, but if allowed to stand unused for some time, an additional capacity may be drawn from the battery at approximately normal voltage.

The capacity of a cell varies a great deal, due to a change in temperature. There is a very marked decrease in the ampere-hour capacity with a decrease in temperature. The battery acts as though it were numbed, due to the cold, and unable to make the same effort that it does at normal temperature. The capacity of the battery will return when its temperature is returned to normal. On account of this decrease in capacity, due to a decrease in temperature, it is always advisable to keep the battery fully charged during the winter or cold months, in order that it be capable of delivering ample energy to meet the requirements. High temperatures are harmful to the life of a storage battery and should always be avoided where it is possible to do so. The high temperature in the cell is usually due to an abnormal condition and an inspection of the battery and system in which it is connected should be made in order to locate the cause of the trouble. If the high temperature is allowed to continue it will distort the plate, permanently injure the wood separators, and more than likely soften the rubber jars and tops to such an extent that they may be seriously distorted.

CHAPTER VIII

Care of Storage Batteries

IN order that a storage battery may give the best service it is possible for it to give, it is necessary that it receive a reasonable amount of care and attention rather than waiting until it is exhausted before the motorist knows there is such a thing as a battery on your car, or how to take care of it. If the following general rules are followed with reasonable care the operation of any good make of lead storage battery should be quite satisfactory.

I—Add nothing but pure water or sulphuric acid electrolyte of the proper specific gravity to the cells. Under no condition try to operate your battery by adding a non-freezing solution of any kind. Water must be added frequently enough to keep the plates covered as they may be seriously damaged if allowed to be exposed for any length of time. It will be found necessary to add water, more frequently in warm weather than in cool or cold weather, and for this reason it is best to make it a rule to remove the vent plugs and add the water once a week.

In freezing or very cold weather, the water should be added just before the car is started in order that the water and electrolyte in the cell may become thoroughly mixed while the battery is charging. The water is lighter than the acid and would remain at the top of the cell and probably freeze, but if charged immediately, the bubbles of gas formed when the cell is charging will serve thoroughly to mix the water and the electrolyte. Be careful not to add too much water as the cell will boil over when it starts to gas and some of the electrolyte will be lost, and it should be replaced with new electrolyte rather than water in order that the specific gravity of the electrolyte in the cell may remain practically constant for a fully charged condition of the cell.

II—The specific gravity of the different cells should be determined at frequent and regular intervals in order to determine if the battery is being properly charged. These hydrometer readings should be taken before adding the water to the electrolyte. In some cases, the electrolyte may be so low in the cell that it is impossible to get enough electrolyte up into the hydrometer syringe to float the hydrometer. Water must then be added and the cell charged for some time in order that the water and electrolyte may mix thoroughly before a hydrometer reading is taken. The condition of charge can be determined by reference to the curve given in Fig. 63, when the specific gravity of the electrolyte is known. If the specific gravity of any one of the cells in the battery is below 1,150, the cell is completely discharged or exhausted and should be removed from the car and given a special charge. In some cases it will be impossible to increase the specific gravity of the electrolyte regardless of the time of charge, which is an indication that there probably is a short circuit inside the cell and in such a case it needs the attention of an experienced battery man.

It occasionally happens that the specific gravity of the electrolyte tests in the neighborhood of perhaps 1,200 although the battery appears to be almost completely discharged as determined by a voltmeter or dim lights. This condition is due to acid having been added to the various cells to replace evaporation instead of adding just pure water, and in addition there is probably some trouble within the cell, such as plates in partial contact, etc. The battery should be given a complete charge, that is it should be charged until the voltage and specific gravity of each cell shows no change in value for a period of several hours. At the end of this charge, take the specific gravity of each cell and if it is above 1,300 draw off some of the electrolyte and add pure water until the specific gravity of all the cells test the same, which should be somewhere between 1,270 and 1,300. If the specific gravity of the electrolyte tests low, withdraw some of it from the cell by means of the hydrometer syringe and add electrolyte having a specific gravity of about 1,300 until the gravity of the electrolyte in the cell has been raised to the desired value. Remember that the cell should be charged for a period after water or electrolyte is added in order that the electrolyte may be mixed thoroughly.

III—Care should be exercised in keeping the outside of the battery clean. It should be wiped off occasionally, and the compartment in which it is placed examined for excessive corrosion due to acid from a leaky cell or perhaps from acid which has run out of the vent hole at the top of the cell. Be careful in cleaning the battery not to get any impurities into the various cells. The connections to the battery should be examined thoroughly at regular intervals to see that they are not working loose or becoming corroded. A rag dampened with weak ammonia may be used to counteract the acid in cleaning about the battery. Hard vaseline may be used to prevent excessive corrosion at the terminals.

Charging the Battery

The best results are obtained in charging a storage battery at such a rate that it will be completely charged in about 8 hours. The battery companies usually specify the rate at which their different types and sizes of cells should be charged and that rate should be followed. This charge should continue until there is no increase in either the voltage of the cell, as indicated by a voltmeter, or the specific gravity of the electrolyte as indicated by the hydrometer for a period of perhaps 5 hours. The electrolyte in the various cells should be gassing, that is, bubbling freely, before the end of the charge.

In some cases, the temperature of the cell may become quite high during charge and, in such cases, it is best either to reduce the rate of charge or to stop the charge entirely until the temperature is lowered to a safe value. Under no conditions should the temperatures of the cell be allowed to exceed 110 degrees Fahrenheit.

If a battery is completely discharged, it may take 20 hours or more to completely recharge it at the normal rate. This time may be reduced where conditions demand that the battery be charged in a shorter time, by charging the battery at twice its normal rate during the first part of the charge and then reducing this rate to normal value as soon as there are any indications of gassing. But it is not recommended as the proper method of procedure to follow in general. The temperature of the cells should be watched carefully and the rate reduced if the temperature rises to the neighborhood of 110 degrees Fahrenheit.

In some cases the temperature may become excessive, although there is little or no gassing in the cells and the specific gravity is low. This is an indication of trouble in the cell and it should be examined by a battery man.

A storage battery must be charged by sending a direct current through it from the positive to the negative terminals. Under no conditions try to charge it by using an alternating current as this will ruin the battery. In some places alternating current only is available, and in such cases it will be necessary to convert the alternating current into direct current. There are a number of different ways of accomplishing this. An alternating-current motor may be operated from the alternating-current circuit and used to drive a direct-current generator which will supply the proper kind of charging current to the battery. A device known as a rectifier may be used to charge the alternating current into direct current. These rectifiers are in general of the mechanical, mercury vapor or electrolytic type.

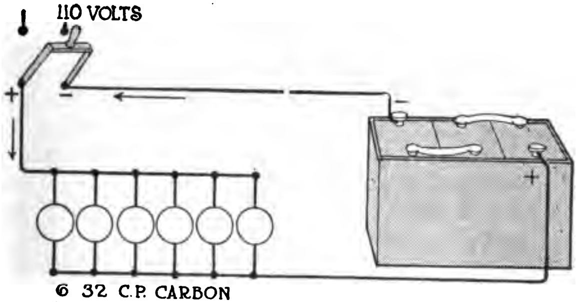


Fig. 65—Connections for charging a storage battery from a 110-volt circuit

If a single 6-volt battery is to be charged from a 110-volt D. C. circuit, connections may be made as shown in Fig. 65. A resistance must be placed in series with the battery, in order to regulate the value of the current and a very convenient resistance is to use a number of 110-volt 32-candlepower carbon-filament incandescent lamps connected in parallel and the combination in turn connected in series with the battery as shown in the figure. Each of the 32-candlepower lamps will allow approximately 1 ampere to pass through the battery, so if the charging rate in amperes is known the number of lamps required will be equal to this rate. When 16-candlepower carbon-filament lamps are used instead of the 32-candlepower ones, twice as many lamps will be required, as each 16-candlepower carbon-filament lamp will allow approximately only ½ ampere to pass through the battery. If high-efficiency lamps, such as tungsten, be used, more lamps will be required as the current rating of the high-efficiency lamps is less than the current rating of carbon-filament lamps.

When a 220-volt circuit is available instead of a 110-volt circuit, two 110-volt lamps must be connected in series as shown in Fig. 66. When a 550-volt circuit is available, five lamps must be connected in series and a sufficient number of these series combinations connected in parallel to give the desired charging current.

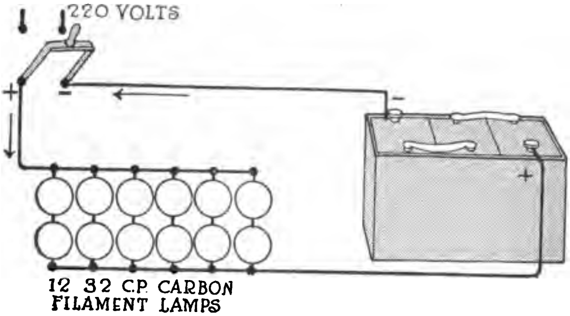


Fig. 66—Connections for charging a storage battery from a 220-volt circuit

Several batteries may be charged in series more efficiently than by charging each battery alone. If several batteries be connected in series in place of the single battery shown in Figs. 65 and 66, less resistance will be required in order that the proper charging current may pass through the batteries. The reason for this is that with an increase in the number of batteries in series there is a decrease in the value of the effective pressure acting in the circuit, which is equal to the difference between the pressure between the terminals of the charging circuit and the combined pressure of all of the batteries, in series, and hence there must be a decrease in the value of the resistance of the circuit in order that the current may remain constant. There is a limit, however, to the number of batteries that may be charged in series and this limit is reached when the combined pressure of all the batteries in series at the end of charge and with the circuit closed is exactly equal to the pressure between the terminals of the charging circuit. Under these conditions there is no resistance required in the circuit and all of the energy drawn from the charging circuit is used within the batteries instead of part of this energy appearing as heat in the resistance.

Care of Battery When Not in Service

It may happen that the battery will be out of service for a considerable period, as when the car is put away during the winter months, and during this time it should not be allowed to stand without attention. If the battery is to be out of service for only 3 or 4 weeks, it should be filled with pure water and given a complete charge the last few days the car is in service by using the lamps and starting motor very sparingly. The specific gravity of the electrolyte should test between 1,270 and 1,300. The batteries should be entirely disconnected from all circuits as any slight leak will in time completely discharge it It should be put in a room whose temperature is fairly uniform and, if possible, in the neighborhood of 70 degrees Fahrenheit.

If the battery is to be out of service for several months, it is perhaps best to send it to a reliable battery station for storage where it will receive the necessary attention from time to time. In some cases, this is not possible and if such is the case you may proceed as follows: Give the battery a complete charge by operating the engine of your car at a speed corresponding to about 20 miles per hour for a sufficient time to cause the battery to become completely charged. If direct current is available, it will be best for you to remove the battery from the car and charge it as outlined in the previous section. From 6 to 8-week intervals during the out-of-service period, water should be added to the cells and the battery given what is known as a refreshing charge; that is, the charge should continue until all the cells have been gassing freely for perhaps 1 hour, and the battery may then be allowed to stand for another similar period without attention. In the event that it is not possible to give the battery a refreshing charge every 6 weeks or 2 months, it may be allowed to stand for a period of perhaps 6 months without any real serious damage resulting, although it is best to give it the refreshing charge or send it to the battery station.

No matter what procedure is followed, water should always be added and the battery fully charged before it is put back into service. If the battery has stood for 5 or 6 months, without being charged, it should be charged for 40 or 50 hours at one-half normal rate before being put back into service.

Chapter IX

Magnets and Magnetism

THE name *magnet* was given by the ancients to certain black stones found in various parts of the world, principally at Magnesia in Asia Minor, which possessed the property of attracting small pieces of iron and steel. Later, the Chinese discovered that if a piece of this black stone were freely suspended by a string it possessed the very remarkable property of pointing always in the same direction, nearly north and south; thence they called the stone ''lodestone,'' or ''leading stone'' and used it in this manner to assist them in navigating their ships. The natural magnet, or lodestone, is an ore of iron, and is called magnetite.

Artificial Magnet

If a piece of iron, or, better still, a piece of hard steel, be rubbed with a lodestone, it will be found to possess the properties or characteristics of the natural magnet; that is, it will attract light pieces of iron; it will point approximately north and south if freely suspended by means of a piece of string; and it can be used to magnetize other pieces of iron or steel. Magnets made in this manner are called artificial magnets.

Strong artificial magnets, however, are not made by using the lodestone, as it is impossible to make them strong enough by this method, but by methods described in a following section on electromagnetism.

Poles of a Magnet

Certain parts of a magnet possess the property of attracting iron and steel to a greater extent than do other parts, and these parts are called the *poles* of the magnet. The poles of a bar magnet are usually situated at or near the ends of the bar, as shown in Fig. 67, which shows a bar magnet that has been dipped into iron filings; the filings are attracted and adhere in tufts at the ends.

North and South Poles

When a magnet is supported on a sharp pivot or suspended by a light thread, it adjusts itself to such a position that it points nearly north and south. A small elongated magnet thus suspended is called a magnetic needle. If such a needle be turned from the position which it naturally takes and is free to swing, it will at once return, swinging to and fro until it settles down in its original position. This tendency of the magnetic needle to set itself approximately north and south is the foundation of the compass.

The end of the needle which points approximately toward the north geographical pole is called the *north* pole, and is usually marked with the letter N; while the other end of the needle is called the *south* pole.

The north pole of a magnet is often called the positive or plus (+) pole, and the south pole is often called the negative or minus (—) pole. Since the north or positive pole turns toward the north, it is sometimes called the *north-seeking* pole, and the south or negative pole is sometimes called the *south-seeking* pole.

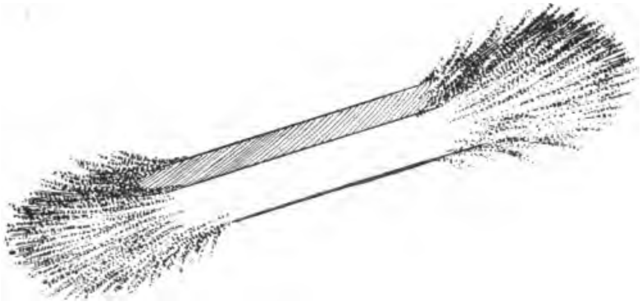


Fig. 67—When a magnet is dipped in iron filings, the filings will cling to the ends of the magnets, which are called poles

Magnetic Attraction and Repulsion

If a pole of a magnet is brought near a magnetic needle, it is found to attract one pole of the needle and repel the other pole. The north pole of the magnet may be determined by observing the position it takes when suspended by a thread and it will be found that the north pole of the magnet always repels the north pole of the needle and always attracts the south pole of the needle. Similarly, it will be found that the south pole of the magnet always repels the south pole of the needle and always attracts the north pole of the needle.

This action shows that there are two kinds of magnetic poles, and that poles of the same kind repel each other and poles of opposite kinds attract each other. The action between two like magnetic poles is shown in Fig. 68, and the action between two unlike magnetic poles is shown in Fig. 69.

Induced Magnetism

If a bar of soft iron be used instead of a magnet, it will be found that either end of the bar of soft iron will attract either pole of the needle. If one end of the iron bar be thrust into a quantity of fine iron filings and withdrawn, only a very few of the filings will adhere to the end of the bar. If, however, one end of the bar be thrust in a quantity of filings and one pole of a permanent magnet be presented to the other end of the bar and the combination then withdrawn, a large number of the filings will adhere to the end of the soft iron bar, as shown in Fig. 70. Practically all of the filings will fall from the end of the soft iron bar if the permanent magnet be removed from the other end. The action between the soft iron bar and the compass needle will increase with a decrease in the distance between them. Similarly, the ability of the soft iron bar to hold the filings will increase as the distance between it and the pole

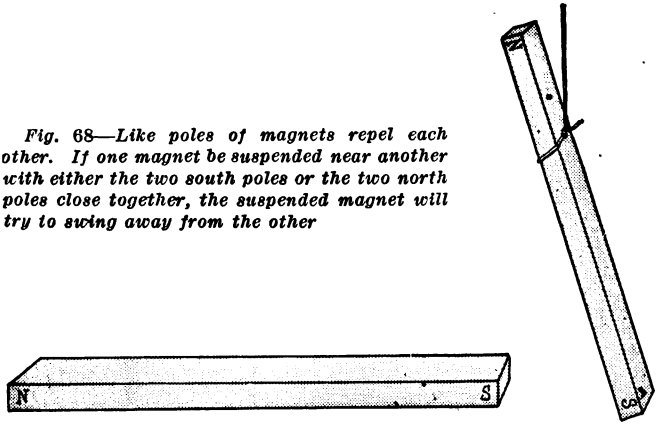


Fig. 68—Like poles of magnets repel each other. If one magnet be suspended near another with either the two south poles or the two north poles close together, the suspended magnet will try to swing away from the other

of the permanent magnet decreases. In either case, the bar of soft iron becomes *magnetized* due to the action of the compass needle or the permanent magnet, and two magnetic poles are produced on it. The end of the bar nearest the magnetic pole on the compass needle, or permanent magnet, will be of opposite sign, while the end of the bar farther away from the compass needle, or permanent magnet, is of the same sign as the pole on the compass needle, or permanent magnet. Magnetism produced in this manner is called *induced magnetism.*

The magnetism induced in a piece of iron may induce magnetism in another piece, and this in another piece, and so on; and thus a magnet may be made to support similar pieces of iron end to end as shown in Fig. 71, each of which has become a magnet by induction. The magnetism of each sucessive piece is weaker than in the preceding piece.

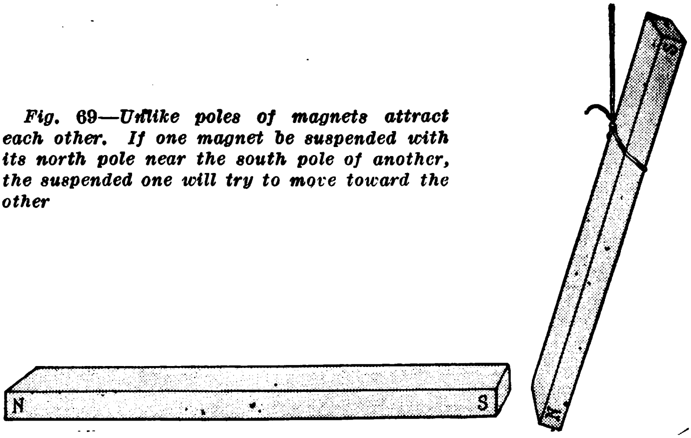


Fig. 69—Unlike poles of magnets attract each other. If one magnet be suspended with its north pole near the south pole of another, the suspended one will try to move toward the other

Forms of Magnets

Magnets are made to assume many different forms, depending in a great measure upon their application. The two principal forms, however, are known as bar and horseshoe magnets, respectively. A bar magnet is shown in Fig. 67 and a common type of horseshoe magnet, as used in the construction of magnetos, is shown in Fig. 72.

A material in which magnetism may be induced, and which is therefore attracted by a magnet, is called a magnetic material. Iron in its various forms, such as wrought iron, cast iron and steel, is the best magnetic material known. There are a few other materials, such as cobalt, nickel and chromium, that are slightly magnetic but very much less than iron. All materials which are not quite strongly magnetic are usually spoken of as non-magnetic materials, since they are nearly neutral as regards magnetism. Unfortunately there is no insulator for magnetism as there is for electricity.

Demagnetization

Continuous jarring of a magnet will tend to cause its magnetism to disappear, or to demagnetize it. If a magnet be heated to a temperature about red heat, it becomes demagnetized, and the iron at the same time, loses its magnetic quality and does not regain it until it cools to a lower temperature. Since a magnet tends to lose its magnetism so readily, it is customary to furnish the horseshoe form with what is called a keeper. The keeper is a piece of iron which may be placed across the poles of the magnet, which makes

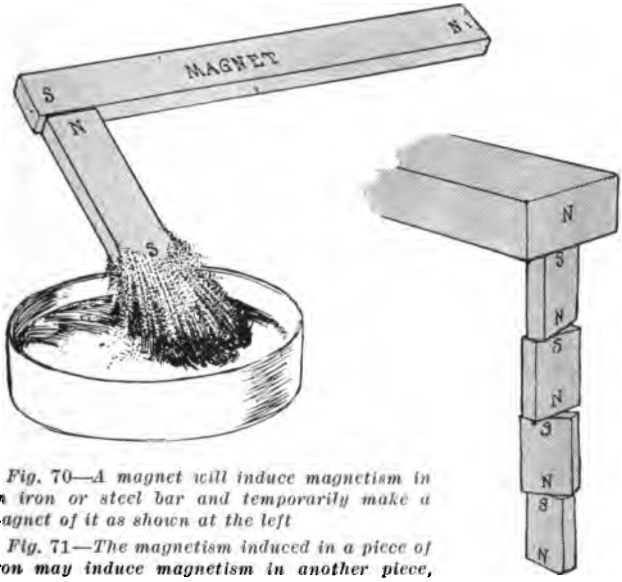


Fig. 70—A magnet will induce magnetism in an iron or steel bar and temporarily make a magnet of it as shown at the left

Fig. 71—The magnetism induced in a piece of iron may induce magnetism in another piece, and that in another, as shown at the right

a complete magnetic circuit and thus tends to prevent the demagnetization of the magnet by jarring.

Coercive Force

Some materials are more readily magnetized and demagnetized than others. For example, it is well known that soft iron is very readily magnetized, but loses practically all of its magnetism if it is slightly jarred after it is removed from the influence of the magnetizing force. Hard steel is usually more difficult to magnetize, but it, on the other hand, does not lose its magnetism so early as soft iron. In general the harder the steel, the harder it is to magnetize and the more strongly it retains its magnetism. The property of a magnetic material which opposes its demagnetization is called its *coercive* force, and it is desirable to have a material of high coercive force in making strong permanent magnets.

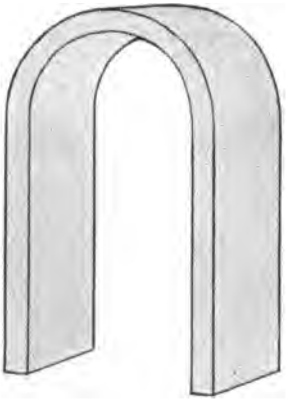


Fig. 72—A horseshoe magnet such as is commonly used in the ordinary magneto for ignition. It is simply a bar magnet of inverted U shape

Retentiveness

When a magnet is magnetized as strongly as possible, it is said to be *saturated,* and if the magnetizing force producing the magnetism be removed, the magnet will immediately grow weaker and it will continue to get weaker for a considerable period until the magnetism finally becomes permanent in strength. Magnets which have lost the temporary magnetism due to saturation are called aged magnets and they should always be used where it is desired to have a constant magnetic effect. The ability of a magnetic material to retain its magnetism after being magnetized is called its retentiveness.

Molecular Theory of Magnetism

There are quite a number of experimental facts which lead to the conclusion that magnetism has something to do with the molecules of the substance, since any disturbance of the molecules causes a change in the degree of magnetization. If a glass tube full of hard steel filings be magnetized, it will behave toward a compass needle or other magnet as though it were a solid bar magnet, but it will lose practically all of its magnetism as soon as the filings are rearranged with respect to each other by giving the glass tube several good shakes. A magnet will lose its magnetism when heated. A magnet may be broken into any number of different pieces and there will appear at each break a north and south pole as shown in Fig. 73. The strength of any magnet will be greatly reduced by hammering, twisting, or bending it.

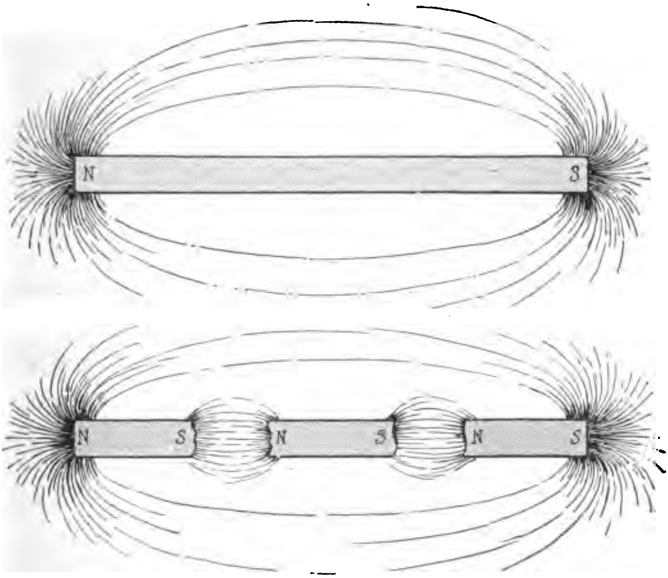


Fig. 73—A magnet may be broken into any number of different pieces and there will appear in each piece a north and a south pole

A theory often used to explain the above facts is as follows: In an unmagnetized bar it is assumed that the molecules are each a tiny magnet and that these molecules, or magnets, are arranged in no definite way, except that the poles of the different magnets neutralize each other throughout the bar. The supposed arrangement of the molecules in an unmagnetized bar is shown in Fig. 74.

When the unmagnetized bar is brought under the influence of a magnetizing force, the tiny magnets are turned, due to the action of the outside magnetizing force, so that their north poles tend to point in one general direction and their south poles tend to point in the opposite direction. The supposed arrangement of the molecules in a magnetized bar is shown in Fig. 75. The opposite poles neutralize each other in the center of the bar but there will be a north pole found at one end and a south pole at the other.

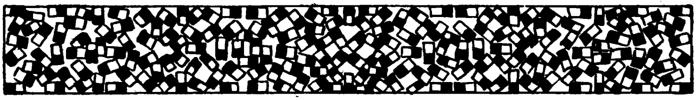


Fig. 74—Assumed arrangement of molecules of iron in an unmagnetized bar

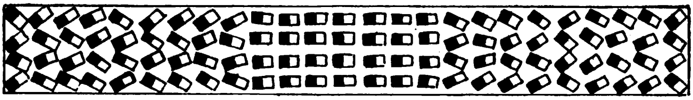


Fig. 75—Rearrangement of molecules in an iron bar, assumed to take place upon magnetization. Each molecule becomes a tiny magnet and all have their north poles pointing approximately one way

The ease with which any material may be magnetized as compared to some other material will depend upon what might be termed the molecular friction of the material. Thus, the molecules in a bar of steel offer a greater resistance to a change in their position than do the molecules in cast iron. Steel, as a result, is harder to magnetize than cast iron, and it will also retain its magnetism after once magnetized better than cast iron for the same reason.

Magnetic Pole of Unit Strength

Some unit of measure must be employed in order to be able to express the strength of a magnet, and for this reason we have what is called a unit magnetic pole. A magnetic pole is said to have a strength of 1 when it will repel a magnetic pole of equal strength and of the same kind with a force of 1 dyne when they are one centimeter apart. There are 2.54 centimeters in 1 inch, and 444,823 dynes in 1 pound, so that the force between two unit poles is very small. In the above definition the magnetic poles are supposed to be concentrated at points. The force acting between two poles will increase with an increase in the value of the product of their respective strengths and decrease as the square of the distance between them.

Magnetic Field

Any open space in which there will be a magnetic force acting on a magnetic material, if it be introduced in the space, is called a magnetic field. Every magnetic field possesses two properties which must be known in order that a magnetic field may be described.

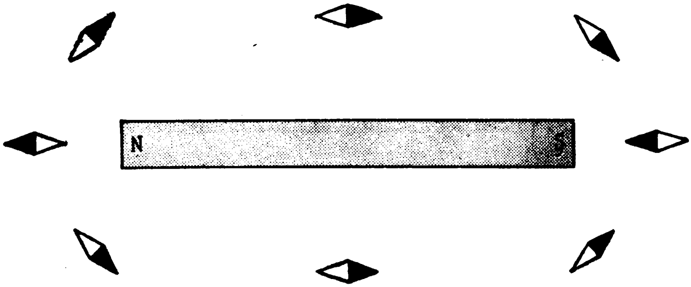


Fig. 76—Direction of magnetic field about a magnet as indicated by a compass

These two properties are the direction of the magnetic field and the strength of the magnetic field.

The direction of a magnetic field is defined as being the direction in which a north magnetic pole would be urged if it were placed in the magnetic field. Since a north magnetic pole cannot be separated from its equal south pole, the direction of the magnetic field may be determined by observing the direction in which the north pole of a short compass needle will point when it is placed in the magnetic field at the point where the direction of the field is desired. For example, the direction of the magnetic field surrounding a bar magnet may be determined as indicated in Fig. 76. The shaded end of the compass needle indicates the north pole of the needle. It will be observed that the direction of the field is out from the north pole of the magnet at one end; it is parallel to the magnet at the center of the magnet and from the north toward the south pole; and toward the south pole of the magnet at the other end.

The strength of a magnetic field at any point is defined as being equal to the force in dynes acting upon a unit magnetic pole placed at the point in question. A magnetic field has unit strength when it exerts a force of one dyne on a unit magnetic pole. A force of one dyne is very small, as there are 444,823 dynes in 1 pound. A uniform magnetic field is one whose strength at every point is the same.

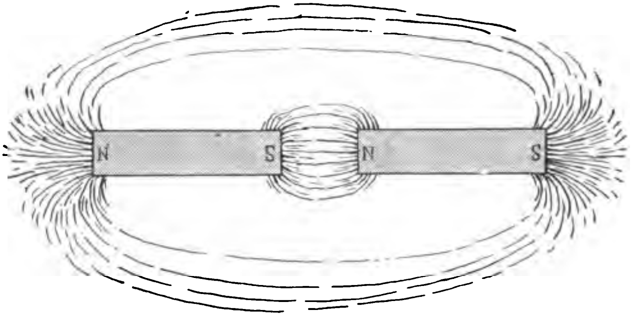


Fig. 77—Lines of force pass from the north pole of one magnet to the south pole of another, when N and S poles are adjacent

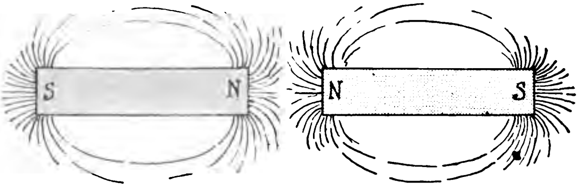


Fig. 78—Lines of force pass between N and S poles of each magnet when N poles are together

Lines of Force

For convenience, a magnetic field is imagined as being a space more or less filled with imaginary lines called *lines of force.* The strength of the magnetic field may be represented by drawing the proper number of these lines of force per square centimeter, the area being taken perpendicular to the direction of the field; and the positive direction of the lines is taken to correspond to the direction of the magnetic field.

These magnetic lines of force which are supposed to constitute a magnetic field are supposed to possess two properties. They always tend to shorten themselves and they repel each other, which in a measure accounts for the attraction between unlike magnetic poles and a repulsion between like magnetic poles. Thus in Fig. 77 the lines of force pass from the north pole of one magnet across the in-

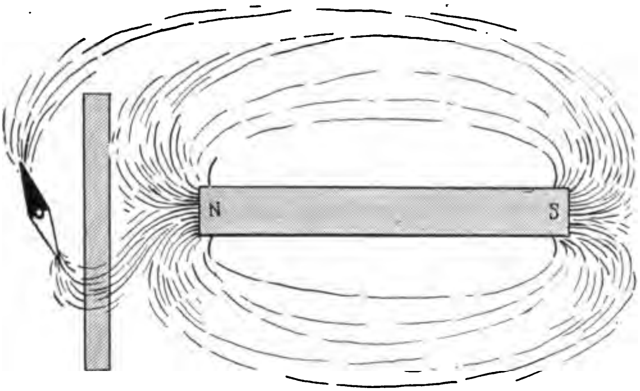


Fig. 79—*A piece of non-magnetic material does not change the effect of a magnet*

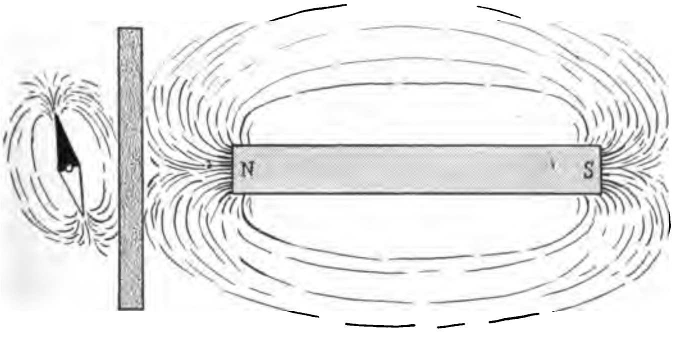


Fig. 80—*A piece of magnetic material prevents the lines of force from the magnet from spreading out* tervening space and enter the south pole of an adjacent magnet. Any tendency of these lines to shorten will result in a force tending to draw the poles together, and any force tending to separate the lines themselves will result in a force tending to draw the two poles together. The action between like poles is shown in Fig. 78.

Magnetic Screen

The effect of a magnet upon a compass needle may be varied by introducing a sheet of magnetic material between the two. The sheet of magnetic material acts as a magnetic screen and prevents the lines of force from the magnet spreading out to the extent they would if no screen were used. Introducing a non-magnetic material, such as glass, between the magnet and compass needle does not interfere with the action of the magnet on the compass needle. The effect of the magnetic and non-magnetic material is shown in Figs. 79 and 80.

Chapter X

Electromagnetism

IF a compass needle be placed near a horizontal conductor in which there is a current of electricity, it will be acted upon by a magnetic force which will tend to turn the needle from its approximately north and south position. The position occupied by the compass needle when it comes to rest will change with a change in the value of the current in the conductor, and also with a change in the distance between the compass needle and the conductor. If the direction of the current in the conductor be reversed and adjusted to exactly the same value as before, the deflection of the compass needle will be changed, and it will be deflected in the opposite direction from its normal position to that before. These experimentally proven facts prove:

First, there is a magnetic field surrounding a conductor in which there is a current of electricity.

Second, the strength of the magnetic field produced by the current depends upon the value of the current.

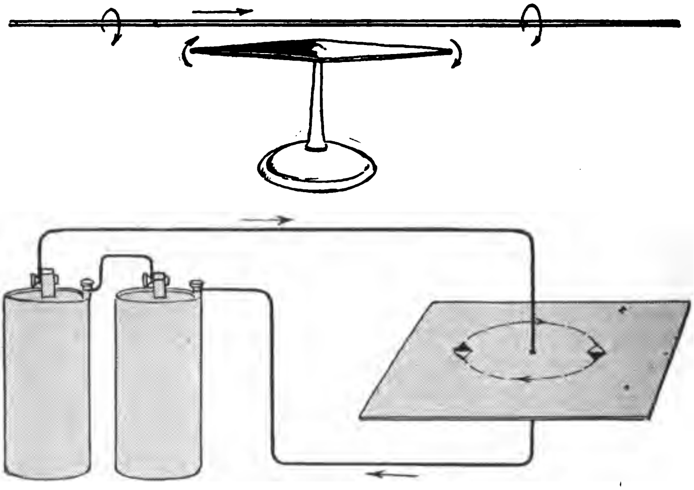
Third, the strength of the magnetic field produced by the current varies with the distance from the conductor.

Fourth, there is a definite relation between the direction of the magnetic field produced by the current and the direction of the current producing the magnetic field.

Magnetism produced in this manner by an electric current is called *electromagnetism.*

Direction of Magnetic Field

The direction of the magnetic field produced by a current of electricity may be determined in exactly the same manner as the direction of a magnetic field due to a permanent magnet, namely, by determining the direction in which the north pole of a compass needle will point when placed in the field at the point where the direction is desired. If a compass needle be placed beneath a wire, as shown in Fig. 81, and a current produced in the wire from left to right, as indicated by the long straight arrow above the wire, the compass needle will move in the direction indicated by the two curved arrows at the ends of the needle. If the compass needle be placed above the wire, it will be deflected in the opposite direction. The general direction of the magnetic field on the under side of the wire is toward the surface of the paper and directly above the wire, the direction of the magnetic field is away from the surface of the paper. If the compass needle be pivoted on a horizontal axis parallel to the wire, instead of a vertical axis as



Figs. 81 *and* 82—*Effect on compass needle of magnetic field about a wire which has a current in it*

in Fig. 81, its north pole will point around the conductor in the same direction as the hands of a clock as you look along the conductor in the direction of the current for all positions in which it is placed. The same results may be obtained by placing the conductor in a vertical position and turning the compass needle around the conductor, the compass needle being free to move in a horizontal plane instead of a vertical plane. If the current in the conductor is down, as shown in Fig. 82, the direction of the magnetic field about the conductor will be clockwise, as indicated by the small arrow heads on the dotted line.

If iron filings be sprinkled upon a sheet of paper through which a conductor passes that is carrying a current, the iron filings will arrange themselves in more or less regular concentric lines, when the paper is gently jarred, as shown in Fig. 83.

Determining the Direction of Magnetic Field

There are a number of simple methods of remembering the relation between the direction of a magnetic field and the direction of the current producing it. A very simple rule, known as the "right-hand rule," is as follows: Grasp the conductor with the right hand, the thumb being placed along the conductor and the fingers around the conductor, then the fingers will point in the direction of the magnetic field when the thumb points to the direction of the current in the conductor.

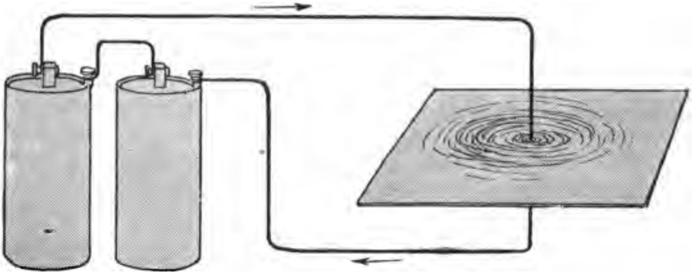


Fig. 83—*Magnetic field about a wire carrying a current shown by iron filings*

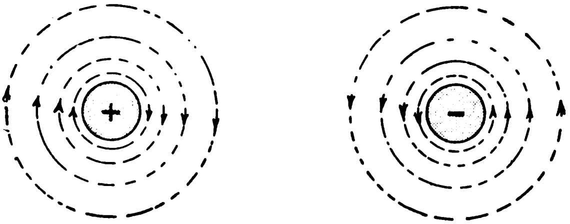


Fig. 84—*The magnetic field is in the same direction as the hands of a clock when the direction of the current is away from the observer* (+) *and anti-clockwise when turned toward the observer* (—)

If you look along a conductor in the direction of the current, the direction of the magnetic field surrounding the conductor, due to the current in the conductor, will be clockwise. Two methods of representing the direction of a magnetic field in relation to the direction of the current in the conductor producing the magnetic field are shown in Fig. 84. A cross-section of the conductor is shown in each case, and a current from the observer is indicated by a plus sign (+), while a current toward the observer is indicated by a minus sign (—). The field is indicated by the concentric dotted circles, and it is clockwise—the same direction as the hands of a clock—when the current is away from the observer and counter-clockwise when the current is toward the observer.

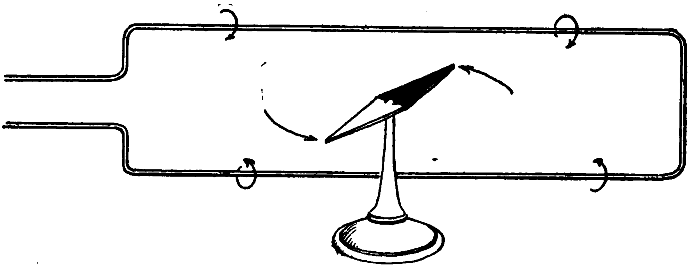


Fig. 85—*Effect on a compass needle of current through a loop of wire*

Another rule, known as the "right-hand screw-rule," is as follows: Consider a right-handed screw which is being screwed into or out of a block. If a current is supposed to exist through the screw in the direction in which the screw moves through the block, then the direction of the magnetic field will correspond with the direction in which the screw turns.

Solenoids

If a conductor be bent into the form shown in Fig. 85 and a current sent through the conductor, the magnetic action on a compass needle placed in the position shown in the figure, due to a certain current in the conductor, will be greater than in the case of a straight conductor. This is due to the fact that the magnetic effect of both the upper and lower portions of the conductor tend to produce a deflection of the compass needle in the same direction. Hence, if the conductor be coiled about the needle, each additional turn will produce an additional force, tending to turn the compass needle from the normal position. The magnetic effect of any current can be greatly increased in this way.

A cross-section through a single turn of wire carrying a current and the magnetic field surrounding the turn are shown in Fig. 86. The current is toward the observer in the left end of the section of wire and away from the observer in the right end of the wire, which results in the direction of the magnetic field about the upper part being counter-clockwise and about the lower part, clockwise. It is obvious that the direction of the magnetic field between the end cross-sections of the wire is downward, and all the imaginary lines of force that are supposed to constitute the magnetic field due to the current in the turn of wire pass through the turn in the same direction.

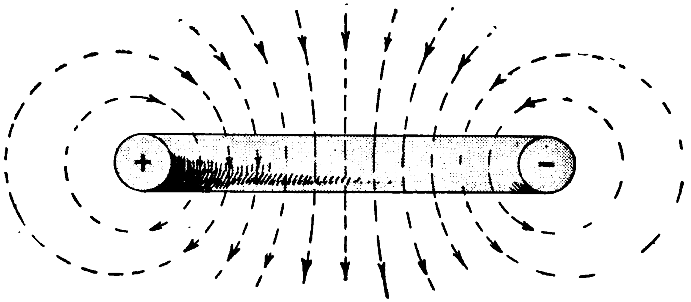


Fig. 86—Lines of force about a turn of wire carrying a current

The magnetic field is stronger in the center of the turn than it is outside, which is indicated by a larger number of lines of force per unit of area, as shown in the figure.

If the number of turns forming the coil be increased, the strength of the magnetic field inside the coil will be increased, since the majority of the lines of force that surround each turn seem to pass around the entire winding instead of passing around the individual turns. A cross-section of a coil composed of a number of turns is shown in Fig. 87. Such a coil is called a *solenoid.*

Polarity of Solenoid

Solenoids carrying current exhibit all the magnetic effects that are possessed by permanent magnets. They attract and repel magnets, pieces of wire and steel, other solenoids in which there is a current, etc. The magnetic lines pass through the solenoid from the south pole to the north pole, and outside the solenoid from the north pole to the south pole, just as in a permanent magnet.

A simple rule by which the polarity of a solenoid may be determined, if the direction of the current in the winding is known, is as follows: If you face one end of the solenoid and the current is around the winding in a clockwise direction, the end of the solenoid nearest you will be the south pole and the other end will be the north pole. If the direction of the current in the winding is counter-clockwise the end nearest you will be the north pole and the other end the south pole.

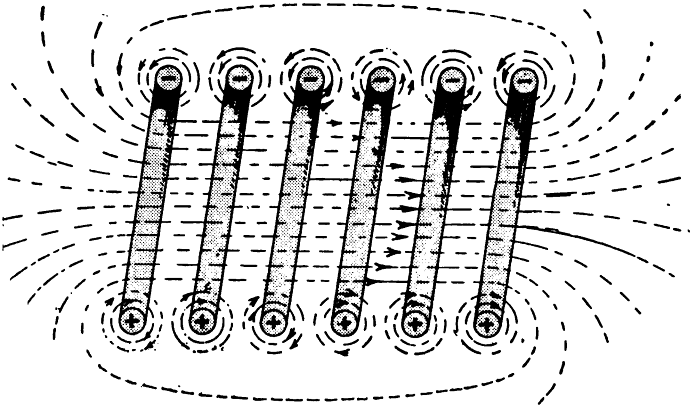


Fig. 87—Cross-section of a solenoid showing lines of force

Another simple rule for determining the polarity of a solenoid is as follows: Grasp the solenoid with the right hand, placing the fingers around it in the direction of the current; the thumb will then point in the direction of the north pole, as shown in Fig. 88.

Magnetomotive Force

When a current of electricity is produced in the winding of a solenoid, it becomes magnetized and lines of force pass through the interior from the south to the north pole and return outside from the north to the south pole. The current produces a force which drives the lines of force, called *magnetic flux,* through the paths which they take, called the *magnetic circuit,* just as the electromotive motive force in the electrical circuit causes the electricity to flow through the electrical circuit. Magnetic flux is measured in a unit called the Maxwell, and one Maxwell simply means 1 ounce of force. This force, due to the electrical current, is called *magnetomotive force,* and it is usually abbreviated to M. M. F.

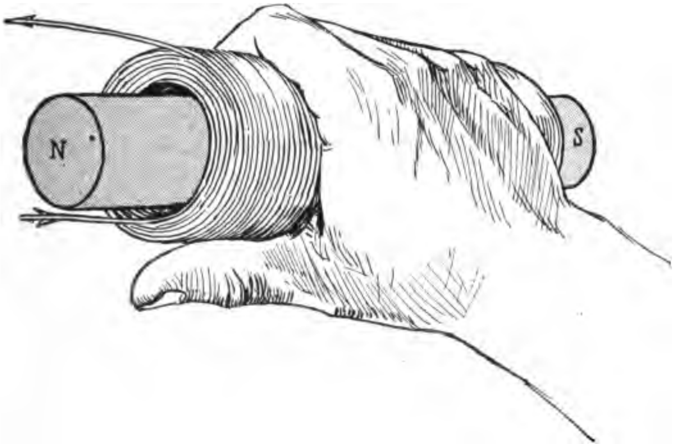


Fig. 88—*Easy method of finding north and south poles of a solenoid. With fingers of right hand in direction of current, thumb points to north pole*

The magnetomotive force of a solenoid is directly proportional to the product of the number of turns in the solenoid and the current in amperes the turns are carrying. If the number of turns in the winding of the solenoid is represented by the letter N and the current in the winding by the letter I, then the magnetomotive force will be greater or less as the product N × I is greater or less. The product of the current and turns is called the *ampere-turns,* and the same magnetomotive force is obtained with a current of 500 amperes through 1 turn, 25 amperes through 20 turns, 1 ampere through 500 turns, etc. In each of the above cases the magnetomotive force is 500 ampere-turns.

In making magneto calculations, magnetomotive force is usually measured in a unit called the Gilbert. If a magnetomotive force is expressed in ampere-turns, it may be expressed in gilberts by multiplying the ampere-turns by 1.2566. Thus the magnetomotive force of 2 amperes in the winding of a solenoid of 50 turns is 100 ampere-turns or 125.66 gilberts.

Reluctance

The magnetomotive force acting on any magnetic circuit encounters a certain opposition to the production of a magnetic flux, just as the electrical pressure encounters a certain opposition in the electrical circuit to the production of an electrical current. The opposition offered by the magnetic circuit is called its *reluctance,* and it is represented by the letter S. The reluctance of a magnetic circuit depends upon the material composing the magnetic circuit and upon the dimensions of the magnetic circuit. It varies directly as the length of the circuit, inversely as the area of the circuit, all other conditions remaining constant, and inversely as a property of the material called its *permeability,* which will be defined later, represented by the symbol M. The unit in which reluctance is measured is called the *oersted.*

Permeability

The number of lines of force passing through each square centimeter of cross sectional area of the solenoid when there is a magnetic core in the solenoid is called the *field strength.* The unit in which the field strength is usually measured is the *gauss,* and it is equal to 1 line of force per square centimeter. Field strength is frequently expressed as so many gilberts per centimeter; that is, it is equal to the magnetomotive force acting on a magnetic circuit divided by the length of the circuit in centimeters. Field strength is represented by the letter H. Any one of the following equations may be used in determining the value of the field strength:

$$H = \frac{\text{total magnetic flux}}{\text{area in square centimeters}} = \frac{\text{maxwells}}{\text{square centimeters}}$$

This equation holds true for a uniform magnetic field but not for a non-uniform magnetic field.

$$H = \frac{\text{magnetomotive force}}{\text{length}} = \frac{\text{gilberts}}{\text{centimeters}}$$

or

$$H = \frac{1.2564 \times \text{ampere-turns}}{\text{centimeters}}$$

If the magnetomotive force of a solenoid having a non-magnetic core can be maintained constant and an iron core be introduced in place of the non-magnetic core, the magnetic flux through the solenoid will be greatly increased.

The number of lines of force per square centimeter in the magnetic material is called the *induction density* and it is usually represented by the letter B. The permeability of a material may be thought of as the ability of the material to conduct magnetic flux as compared to air. In making up a good magnetic circuit, it is always desirable to have materials of high permeabilities, in order that the reluctance of the magnetic circuit may be low.

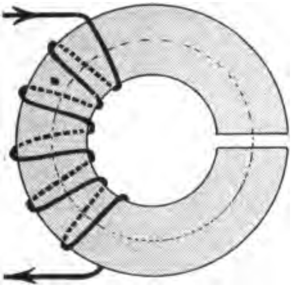


Fig. 89—*Two reluctances in series*

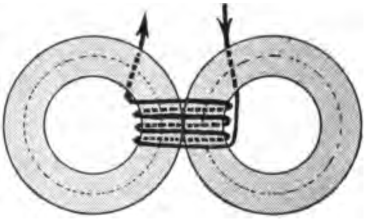


Fig. 90—*Two reluctances in parallel*

Ohm's Law for the Magnetic Circuit

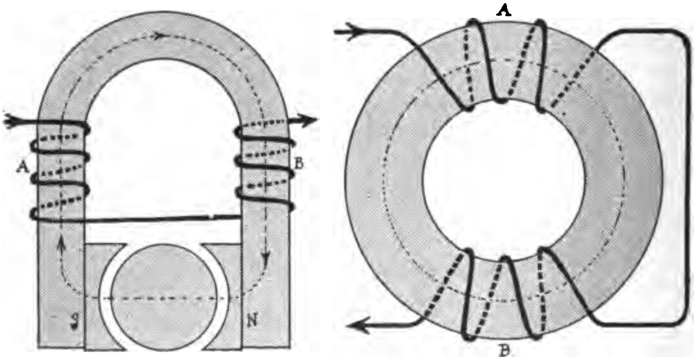
The magnetomotive force acting as a magnetic circuit, the reluctance of the circuit, and the magnetic flux produced are related to each other just as the electrical pressure in an electrical circuit, its resistance and the current produced are related to each other. This relation may be expressed as follows:

$$\text{Magnetic flux} = \frac{\text{magnetomotive force}}{\text{reluctance}}$$

Reluctance in Series and Parallel

A magnetic circuit may be composed of several reluctances connected in series or parallel or a combination of the two methods just as an electrical circuit may be composed of several resistances connected in series or parallel or a combination of the two methods.

If an air gap be cut in an iron ring, as shown in Fig. 89, the magnetic circuit composed of the iron ring and air gap will constitute a magnetic circuit in which two reluctances are in series.



Figs. 91, *right, and* 92, *left—Magnetomotive forces and reluctances in series*

The total reluctance of such a circuit is equal to the sum of the reluctances of the different parts, just as the total resistance of a series electrical circuit is equal to the sum of the resistances of the different parts.

If two iron rings be placed side by side and a winding placed about both of them, the two rings will constitute a magnetic circuit in which two reluctances are in parallel. The two rings and winding may be arranged as shown in Fig. 90, but the reluctances of the two rings are still in parallel.

Magnetomotive forces in series and parallel magnetomotive forces may be connected in series and parallel just as electromotive forces may be connected in series and parallel. For example, the magnetomotive force of winding A in Fig. 91 is acting on the same magnetic circuit as the magnetomotive force of winding B. If these two magnetomotive forces both tend to produce a magnetic flux around the iron ring in the same direction, the total magnetomotive force acting on the magnetic circuit will be equal to the sum of the two. If, however, the two magnetomotive forces tend to produce a magnetic flux around the iron ring in opposite directions, the total or effective magnetomotive force acting on the magnetic circuit will be equal to the difference between the two magnetomotive forces. The direction of the effective magnetomotive forces will correspond to the direction of the larger of the two magnetomotive forces.

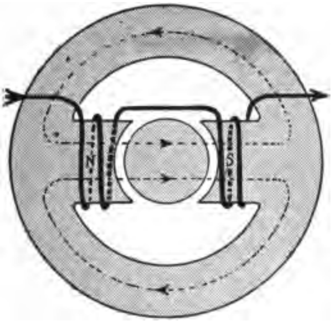


Fig. 93—*Two magnetomotive forces in series acting on two reluctances in parallel*

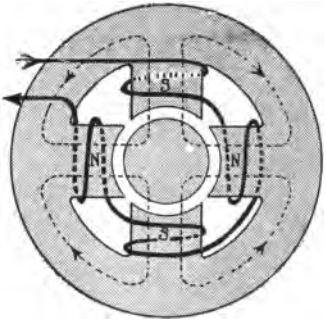


Fig. 94—*Magnetic circuits of a four-pole generator*

The magnetic circuit shown in Fig. 92 is composed of a number of reluctances in series and two magnetomotive forces in series. Two magnetomotive forces are shown acting in series on two magnetic circuits connected in parallel in Fig. 93. The magnetic circuits of a four-pole generator or motor are shown in Fig. 94. In Figs. 87 to 94, inclusive, the dotted lines indicate the path of the lines of force. The magnetomotive force acting on each of the magnetic circuits in Fig. 94 is equal to the sum of the magnetomotive forces of the two coils wound around the circuit. Each coil is connected to two magnetic circuits in Fig. 94 and only one-half as many ampere-turns are required in each coil with this arrangement as would be required if the coils were wound around the outside portion of the magnetic circuits and around a single circuit instead of two.

Hysteresis

If a piece of iron be magnetized and the magnetizing force then removed, the induction density does not return to zero value. A magnetizing force must then be applied in the opposite direction in order to demagnetize the iron. The induction density may be built up to the original maximum value but in the opposite direction by increasing the magnetizing force. This lag of the induction density behind the magnetizing force is called *hysteresis.*

This hysteresis property of the iron is supposedly due to a molecular friction in the iron, and it results in the iron heating when it is rapidly magnetized and demagnetized. Certain grades of iron show a less hysteresis property than others and the manufacturers of electrical equipment endeavor to use this kind of iron, all other conditions being equal, when the iron is subjected to a rapid magnetization and demagnetization in the operation of the apparatus.

CHAPTER XI

Electromagnetic Induction

ABOUT 1831, Michael Faraday discovered that an electrical pressure was produced in a wire that was moved in a magnetic field, when the direction of the motion of the wire was such that it moved across the imaginary lines of force forming the magnetic field. If this wire be made a part of a closed electrical circuit, the electrical pressure produced in the wire will cause a current of electricity in the circuit. Electrical pressures produced in the above manner are called *induced pressures or induced electromotive forces,* and an electrical current produced by an induced electromotive force is called an *induced current,* and the phenomenon is called *electromagnetic induction.* In this great discovery lies the fundamental principle of the operation of many forms of ignition, starting and lighting apparatus such as magnetos, electrical generators, induction coils, etc.

Currents Induced in a Wire by a Magnet

If a wire AB, Fig. 95, that is connected in series with a galvanometer—an exceedingly sensitive ammeter—be moved in the magnetic field of a magnet, the needle will be deflected from the zero position. This deflection of the galvanometer is due to a current in its winding which is produced by the induced electromotive force in the wire that is moved in the magnetic field. When the movement of the wire in the magnetic field ceases, the galvanometer will show no deflection, which indicates there is no current and hence no induced electromotive force. Hence, the wires must be actually cutting the lines of force that are supposed to form the magnetic field in order that there be an induced electromotive force produced in the wire.

If the wire were moved to the left, as indicated by the arrow C, across the magnetic field and the deflection of the galvanometer happened to be to the left, it will be found upon moving the conductor to the right, as indicated by the arrow D, or in the direction opposite to its motion in the first case, that the galvanometer will be deflected in the opposite direction from its zero position. Since the direction in which the indicator of a galvanometer is deflected depends upon the direction of the current through its winding, it is very apparent that the direction of the circuit in the second case is opposite to what it was in the first case; and, since the current is due to the induced electromotive force in the wire, it must also be in the opposite direction. If the motion of the wire in the magnetic field is continuous right and left, between the ends of the magnet, there will be a current through the galvanometer first in one direction and then in the opposite direction and the moving part of the galvanometer will swing to the right and left of the zero position. The motion of the wire, however, may be rapid enough so that the moving part of the galvanometer has not sufficient time to take its proper position with respect to the current in the circuit, and as a result it remains practically at zero, the movement or deflection to the right or to the left being very small.

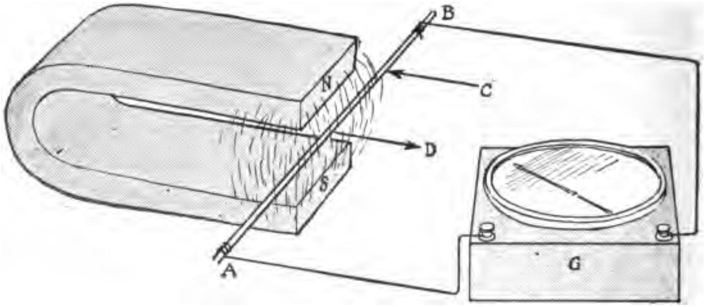


Fig. 95—*If a wire is moved in the field of a magnet, an electrical pressure is generated in the wire*

The same results can be obtained when the magnet is turned over and the south pole is at the top and the north pole at the bottom, except that the deflection of the galvanometer due to a given direction of motion of the wire will be just the reverse of what it was with the magnet in the original position. This shows that there is some definite relation betwen the direction of motion of the conductor, the direction of the magnetic field and the direction in which the induced pressure acts.

If the wire were held stationary and the magnet moved, the same results would be obtained as though the wire were moved between the poles of the magnet with the magnet stationary. Hence, it is only necessary that there be a relative movement of the wire and the magnetic field; either may remain stationary.

An electromagnet may be used instead of a permanent magnet and the same results will be obtained under quicker conditions.

If the wire be moved very slowly across the magnetic field, the galvanometer will be deflected to a smaller extent than it would be if the wire were moved faster across the magnetic field. This deflection of the galvanometer depends upon the value of the current sent through it and since the deflection is smaller when the wire is moved slowly than it is when the wire is moved fast, it must follow that the induced pressure for a slow movement of the wire is less than it is for a fast movement, even though all the magnetic lines forming the magnetic field be cut in each case. The above experimentally determined results show that the value of the induced electromotive force in a wire, due to a relative movement of a wire and a magnetic field, depends upon the velocity of the wire. If a second wire be connected in series with the first, so that the induced electromotive forces act in the same direction, the resultant, or effective, electrical pressure is increased. This is equivalent to increasing the length of the wire in the magnetic field.

The electrical pressure may be increased by placing a second magnet along the side of the first so that the like poles are adjacent. This second magnet increases the strength of the magnetic field and the wire cuts more lines of force when it is moved.

If the wire be moved in a path parallel to the lines of force forming the magnetic field there will be no deflection of the galvanometer, which indicates there is no current in the circuit and hence no induced electrical pressure produced in a wire due to its movement with respect to a magnetic field. The path in which the wire moves must make some angle with the direction of the magnetic lines of force. The value of the induced pressure due to the movement of a wire and a magnetic field with respect to each other will increase as the angle between the direction of the lines of force and the path in which the wire moves increases, and it will be a maximum when the wire moves in a path perpendicular to itself.

There will be an induced pressure set up in the wire even though the circuit of which the wire forms a part be open. This induced pressure will exist between the terminals of the circuit where it is opened just the same as an electrical pressure exists between the terminals of a battery that is on an open circuit.

The question arises: Is the magnet weakened when it is used in producing induced pressures in a wire and if not, what is the source of energy that causes the current to exist in the wire? The magnet is in no way weakened when it is used as described and the induced current is produced by the expenditure of muscular energy in moving the wire, just as the expenditure of chemical energy in a cell produces an electrical current in a closed electrical curcuit in which the cell is concealed.

When a wire with a current in it is located in a magnetic field there is a force acting on the wire which tends to cause the wire to move across the field. The direction of this force is just the opposite to the one that must be applied to the wire to cause it to move, so there will be an induced pressure set up in the wire which will produce the current. In other words, the induced pressure set up in a wire will always be in such a direction that the current produced by it will oppose the motion of the wire.

Current Induced in a Coil by Moving a Magnet

If a coil of wire be connected in series with a galvanometer as shown in Fig. 96, a deflection of the galvanometer indicator can be produced by thrusting the magnet in and out of the coil. The fact that part of the galvanometer indicator is deflected when the magnet is moved inside the coil is proof that there is a current produced in the circuit and it must be due to an induced pressure. When the magnet is thrust into the coil, a deflection of the galvanometer indicator will be produced, say, to the right, and when the magnet is withdrawn the galvanometer indicator will move to the left. If the magnet be turned end for end, the deflections of the galvanometer indicator will be just the reverse. If the coil itself be turned end for end and the magnet placed in its original position the deflection of the galvanometer indicator produced by a movement of the magnet in or out of the coil will correspond in direction to those produced when the coil was in its original position and the magnet had been turned end for end.

If the coil be moved on or off the magnet, the same results will be obtained as when the magnet was moved in or out of the coil. The value of the induced pressure in this case, as in the previous one when the wire was moved in the magnetic field, will depend upon the velocity with which the magnetic field and coil move with respect to each other.

If the number of turns of wire composing the coil be increased or decreased, there will be a corresponding increase or decrease in the value of the induced pressure in the winding of the coil due to a given movement of the coil and magnet with respect to each other. The induced pressure in the various turns of the coil will all act in the same direction, and the effective pressure is equal to the sum of the induced pressures in the various turns. The induced pressure in each of the turns will have the same value at any instant, provided each turn is cutting the same number of lines of force at that particular instant.

Value of the Induced Pressure

From the discussion above, it is seen that the induced pressure in an electrical circuit depends upon the following things:

(a) The velocity of the wire and the magnetic field with respect to each other. The greater the velocity, the greater the induced pressure, all other things remaining constant.

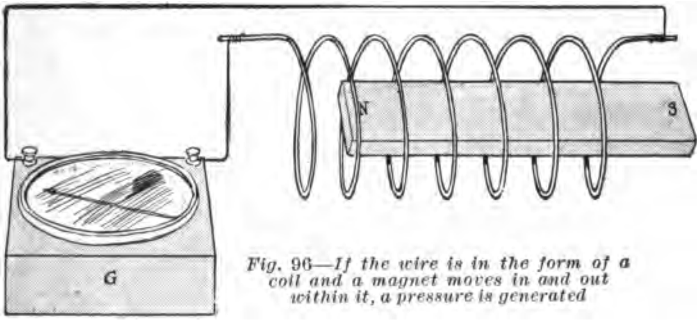


Fig. 96—If the wire is in the form of a coil and a magnet moves in and out within it, a pressure is generated

(b) The strength of the magnetic field, that is the number of lines of force per square centimeter. The stronger the field, the greater the induced pressure, all other things remaining constant.

(c) The angle the path in which the wire moves makes with the direction of the magnetic field. The nearer this path is to being at right angles with the direction of the magnetic field and the axis of the wire, the greater the induced pressure.

(d) The length of the wire actually in the magnetic field. The more wire there is in the magnetic field, the greater the induced pressure, all other things increasing constant.

All of the above facts can be condensed with the following simple statement: The value of the induced pressure in any electrical circuit depends upon the rapidity with which the wire forming the circuit cuts magnetic lines of force; that is, it depends upon the number of lines of force cut per second by the wire.

When the wire cuts one hundred million lines in each second during its movement with respect to the magnetic field, an electrical pressure of 1 volt will be induced in the wire.

If the wire cuts line of force at the rate of two hundred million lines of force per second, the induced pressure will be 2 volts; and if the wire cuts six hundred million lines of force per second, there will be an induced pressure of 6 volts. If the circuit in which this induced pressure is produced be closed, there will be a current produced equal in value to the induced pressure divided by the total resistance of the circuit.

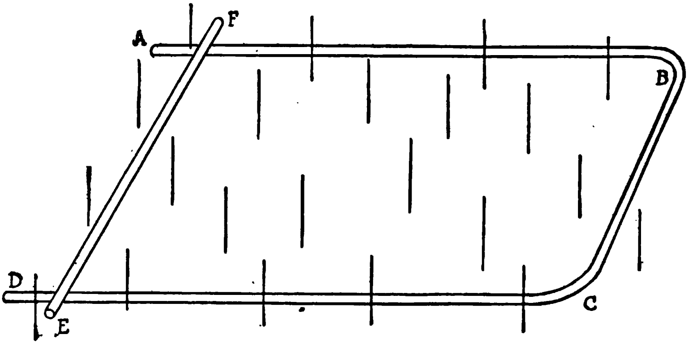


Fig. 97—Direction of induced current depends upon direction of motion

Example: A wire cuts across a magnetic field of 10,000,000 lines of force 60 times per second. (The conductor always moves across the field in the same direction.) What is the value of the pressure induced in the wire?

Solution: A wire cutting 10,000,000 lines of force 60 times per second is equivalent to a conductor cutting 60×10,000,000, or 600,000,000 lines of force once per second. If a conductor cuts 600,000,000 lines of force per second, the value of the induced pressure will be equal to 600,000,000 divided by 100,000,000 or 6 volts.

Direction of Induced Pressure

From the previous discussion, it is seen that the direction of the induced pressure depends upon the direction of the magnetic field and the direction in which the conductor is moved with respect to the magnetic field. If a metal rod be bent into the form shown by A B C D, Fig 97, and a second rod E F be placed across the ends of the first rod and the combination placed in a magnetic field as shown by the vertical arrows in the figure, there will be a current around the circuit thus formed when the conductor E F is moved to the right or to the left of the initial position. When the conductor E F is moved, it cuts some of the lines of force of the magnetic field and there is an induced pressure produced in it which in turn produces the current. The direction of this current will be increased where the direction of the motion of E F, or the direction of the magnetic, is reversed.

When the wire E F is moved to the right, the end F is positive and the other end E is negative, or the electrical pressure induced in the wire tends to send a current around the circuit from F through B and C to E. The wire E F is the part of the circuit in which the pressure is generated and the electricity will flow from a point of one pressure to a point of higher pressure just as in the case of the battery.

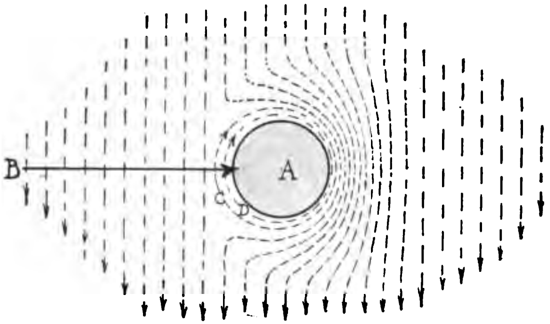


Fig. 98—The lines of force might be thought of as elastic bands that are pushed aside when the wire is moved, then break and join on the other side

Determining the Direction of Pressure

A simple way of determining the direction of the induced pressure when the direction of motion of the wire and the magnetic field are known is as follows: Suppose a wire A, Fig. 98, is moved toward the right, as indicated by the horizontal arrow B, in a magnetic field where direction is downward, as shown by the small arrow heads at the bottom of the figure. The lines of force might be thought of as elastic bands that are pushed aside when the wire is moved in the magnetic field, but finally break and join on the left side of the wire, leaving a line linked around the conductor as shown by the circles C and D. The direction of these lines of force about the conductor is clockwise and they correspond to lines produced by a current toward the paper, or away from the observer. Hence, the direction of the induced electrical pressure is toward the paper. It must be remembered that the electricity travels up hill electrically in this part of the circuit just as in the case of a cell.

One of the best rules for remembering the relation between the direction of the magnetic field, the direction in which the wire moves and the direction of the induced electrical pressure is known as Pleming's Right-Hand Rule and it is as follows: Place the thumb and first and second fingers of the right hand all at right angles to each other. Now turn the hand into such a position that the thumb points in the direction of the motion of the wire and the first finger points in the direction of the magnetic field, then the second, or middle, finger will point in the direction of the induced pressure. An illustration of the Right-Hand Rule is shown in Fig. 99.

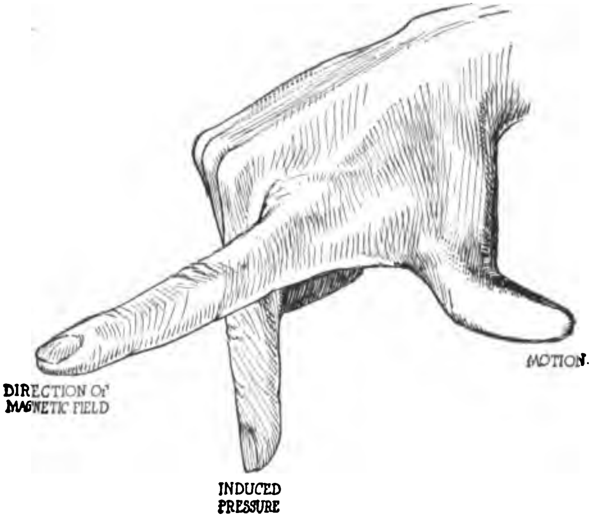


Fig. 99—*The right-hand rule for finding the direction of induced currents*

Primary and Secondary Coils

If a coil of wire S be connected in series with a galvanometer as shown in Fig. 100, and a second coil P that has the winding connected to a battery be moved into or out of the coil S, there will be a deflection of the galvanometer, just as though a permanent magnet had been used instead of the coil P. The coil S, in which the induced pressure is produced, is called the *secondary* and the coil P, in which the inducing current exists, is called the *primary.*

There are a number of different ways of producing an induced pressure in the secondary coil besides moving the primary coil with respect to the secondary coil. Four of these methods are as follows:

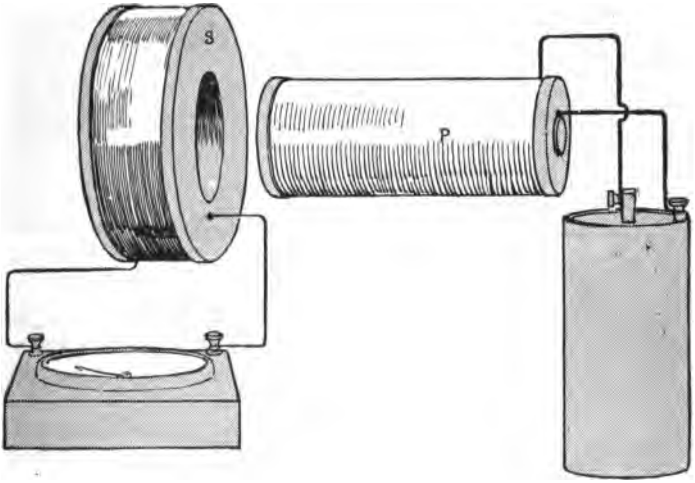


Fig. 100—*The coil S, in which the induced pressure is produced, is the secondary, and the coil P, in which the inducing current exists, is the primary coil*

(Both coils are stationary and one surrounds the other or they are both wound on the same magnetic circuit.)

(a) By making or breaking the primary circuit: Imagine two wires A B and C D, Fig. 101, that are parallel to each other and very near together but connected in two electrically independent circuits. The wire A B is in series with the galvanometer G and constitutes the secondary circuit. The wire C D is in series with a battery E and a switch K which may be used in opening and closing the primary circuit. When the primary circuit is completed by closing the switch K there will be a current through the wire C D from C toward D. This circuit will produce a magnetic field about the wire C D and the lines of force of this magnetic field will cut the wire A B, which will result in an induced pressure being produced in the wire A B and causing a current from A toward B. The direction of the induced pressure can be determined by means of the Right-Hand Rule. There will be an induced pressure produced in the wire A B for a period of time corresponding to the time required to establish the current in the primary. As soon as the current in the primary becomes steady there will be no movement of the magnetic field and the conductor A B with respect to each other. When the current in the wire C D is increasing in value, the magnetic field surrounding the wire is expanding and moving outward across the conductor A B.

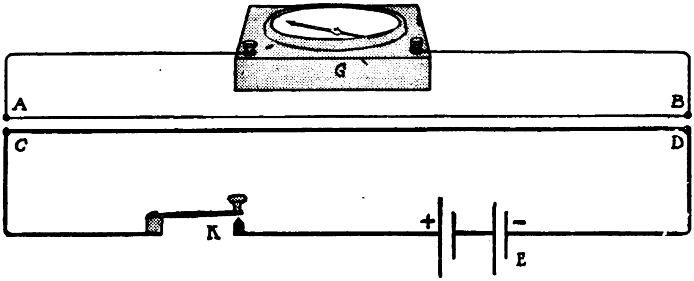


Fig. 101—*How current is produced in an induction coil*

If, now, the primary circuit be broken, the magnetic field surrounding the wire C D will collapse and, as a result, the wire A B will cut the magnetic field again, but in the opposite direction to that when the current in the wire C D was being established. There will be a current produced in the secondary circuit that is practically constant in duration, if the primary circuit is made and broken a sufficient number of times. The current produced in the secondary circuit is called an alternating current because it alternates in direction, it being in one direction when the current in the primary is increasing in value and in the opposite direction when the current in the primary is decreasing in value.

The wires forming the primary and secondary circuits are usually wound into coils, and they may be placed side by side or one outside the other. The pressure induced in the secondary due to a given change of current in the primary in a certain time can be greatly increased by placing the two windings on an iron core. The magnetic field that passes through the two windings, due to the current in the primary, is a great deal stronger when they are placed on the iron core than it is when an air core is used and, as a result, a greater number of lines of force will cut the secondary winding when the primary circuit is completed or broken.

The induction coil consists of two windings, a primary and a secondary placed upon an iron core with a suitable device connected to the primary circuit for interrupting the primary current. The relation between the pressure acting on the primary winding and the induced pressure produced in the secondary winding is practically the same as the relation between the number of turns of wire in the primary and secondary windings.

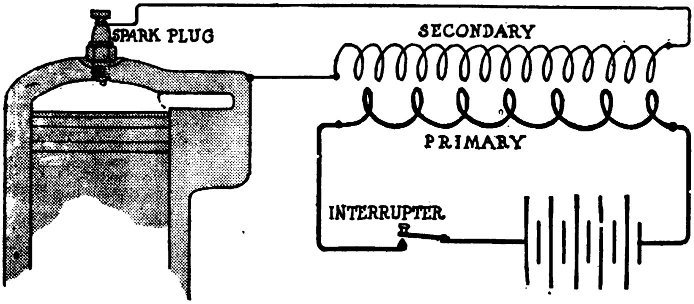


Fig. 102—*How the induction coil is applied to the ignition of a motor car engine*

This is the method used in the simplest battery and coil ignition system as illustrated in Fig. 102. The spark plug in Fig. 102 replaces the galvanometer in Fig. 101 and the interrupter, or circuit breaker, replaces the switch K. The interrupter simply is an automatic switch which rapidly opens and closes the circuit. The wire between A and G in Fig. 101 is replaced in the ignition system by the metal of the engine between the spark plug and the coil terminal as shown in Fig. 102.

(b) Varying the strength of the current in the primary: This in reality is practically the same as the previous method except the primary circuit is not entirely opened. Any change in the value of the primary current will result in a change in the magnetic field surrounding the primary winding and as this field expands or contracts, it will cut the wire composing the secondary circuit and as a result there will be an induced pressure set up in the secondary winding. The direction of this induced pressure will depend upon whether the field is expanding or contracting, which, in turn, depends upon the change of current in the primary winding—whether it be increasing or decreasing.

(c) Reversing the current in the primary: If a switch were constructed so that its operation would reverse the current in the primary winding of an induction coil at regular intervals, there would be an induced pressure produced in the secondary winding due to a change in the strength of the magnetic field through the two windings. This method is applied in practice in what is called the transformer. The switch, however, is not used as the current in the primary winding is an alternating current, a current that is reversing in direction at regular intervals.

(d) Moving a portion of the magnetic circuit about which the windings are placed: The magnetic field produced by a given value of current in the primary winding of an induction coil will depend upon the kind of material composing the magnetic circuit, whether it is a material of low or high permeability. If the core upon which the windings are placed or a part of the magnetic circuit be moved so as to change the resistance of the magnetic circuit, there will be a change in the number of lines of force through the windings and, as a result, there will be an induced electrical pressure produced in the windings. If the resistance of the magnetic circuit be increased, there will be a decrease in the number of lines of force, and if the resistance be decreased there will be an increase in the number of lines of force, all other things remaining unchanged. When the lines of force through the windings decrease, there will be an induced pressure set up in the windings in the opposite direction to that set up when the magnetic lines of force increase. This principle is employed in what are called the inductor types of magnetos.

Mutual Induction

The reaction of two independent electrical circuits upon each other is called *mutual induction.* These circuits must be so placed with respect to each other that the magnetic field due to the current in either of them will produce an effect in the other. The induction coil, or ignition spark coil, is a fine example of the practical application of mutual induction.

If the value of the current in a wire be changed in any way there will be a change in the strength of the magnetic field surrounding the wire. This change in the strength of the magnetic field will produce an induced pressure in the wire in which the current is changing in value just as though the magnetic field were changed in strength by a current in an independent electrical circuit. This property of a circuit which results in an electrical pressure being produced in the circuit when there is a change in the value of the current in the circuit is called the *self inductance* of the circuit. When a coil carrying a current has its circuit broken, there will be a spark formed at the break due to the induced pressure. The value of this induced pressure depends upon the form of the coil and the kind of material associated with the coil. A straight wire will have a small pressure induced in it when the circuit is broken, as the magnetic field surrounding the wire is not very strong. If the wire be bent into a coil, the induced pressure will be greater than that for the straight wire, as very nearly all the magnetic lines of force produced by each turn of the coil cut all the other turns of the coil and the total number of lines of force cut by the wire forming the coil is greatly increased. This induced pressure can be increased further by providing the coil with an iron core, which increases the field strength caused by any given current in the winding.

In make-and-break ignition, it is desirable to have a hot spark at the point where the circuit is broken inside the cylinder, and for this reason a coil having a rather high self inductance is usually connected in series, which results in a large arc or spark being formed when the circuit is broken.

Unit of Inductance

A circuit is said to have a self-inductance of 1 henry when there is an electrical pressure of 1 volt induced in the circuit due to a change in the value of the current in the circuit of 1 ampere in 1 second. That is, if the current changes, say, from 2 to 3 amperes in 1 second and there is an induced pressure of 1 volt, the circuit is said to have a self inductance of 1 henry.

The mutual inductance between two circuits is measured in the same unit as the self inductance of a single circuit. If the current in one circuit changes at the rate of 1 ampere per second and as a result of this change there is an induced pressure of 1 volt produced in a second circuit, the two circuits are said to have a mutual inductance of 1 henry.

CHAPTER XII

Generators and Motors

A DYNAMO is a machine for converting mechanical energy into electrical energy or electrical energy into mechanical energy by means of electromagnetic induction. The dynamo, when used to transform mechanical energy into electrical energy, is called a *generator*, and when it is used to transform electrical energy into mechanical energy, it is called a *motor*. Bear in mind that the generator does not create electricity, but simply imparts energy to it, just as energy is imparted to the electricty as it passes through the primary cell.

The dynamo consists, fundamentally, of two parts—a magnetic field, which may be produced by permanent magnets or electromagnets, and an armature, which consists of a loop of wire or a number of loops, usually wound or mounted on an iron core or frame and so arranged that there may be a relative movement of the magnetic lines of force forming the magnetic field and the loop of wire. The movement of the loop of wire and the magnetic lines of force with respect to each other results in there being an electrical pressure produced in the loop.

Simple Alternator

If a single loop of wire is revolved in the magnetic field of a permanent magnet as shown in Fig. 103, there will be an electrical pressure induced in the two sides of the loop. If the terminals of the loop be connected to two metal rings C and D upon which brushes rest, this induced electrical pressure will produce a current in a circuit, such as a lamp, when it is connected to the brushes. The direction of the induced electrical pressure in the two sides of the loop may be determined by a simple application of Fleming's generator rule, as given in a previous installment.

The motion of one side of the loop with respect to the magnetic field is just the reverse to the motion of the other side. As a result of this difference in motion of the two sides of the loop with respect to the magnetic field, the electrical pressure induced in a side of the loop will be from the observer, while that induced in the other side will be toward the observer. These electrical pressures are in series and since their directions are opposite with respect to the observer, they both tend to produce a current in

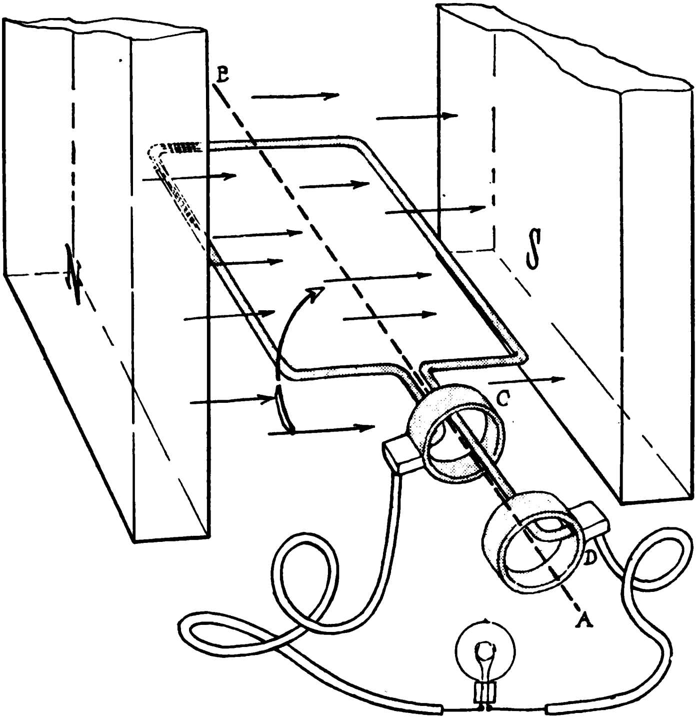


Fig. 103—*The principle of the generator. This is the simplest alternating-current generator, in which a loop of wire is revolved about an axis A B in a magnetic field represented by the arrows passing between the poles N and S of a magnet. The induced current caused by the wire cutting the lines of force is taken off the collector rings C and D by brushes to which the outside circuit is connected* the same direction around the loop. There will be no induced electrical pressure in the ends of the loop since they cut no lines of force.

The electrical pressure induced in either side of the loop at any instant will depend upon the number of magnetic lines cut in one second, or the rate at which the lines are being cut. This rate of cutting of the magnetic lines will depend upon the length of the two sides of the loop in the magnetic field, the strength of the magnetic field and the number of revolutions per second. Assuming the strength of the magnetic field is uniform, that it is the same at every part of the field and it remains constant in value, and the loop revolves about its axis at a constant speed, then the induced pressure in the loop will change in value, due only to a change in the direction of motion of the two sides of the loop with respect to the magnetic field.

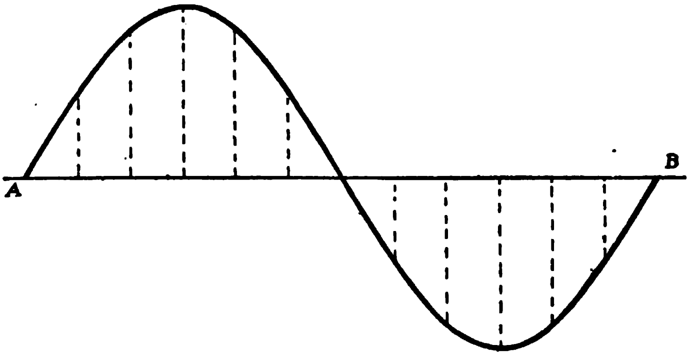


Fig. 104—*Curve showing the variation of electrical pressure induced in a loop of wire when it is revolved in a magnetic field. This represents a complete revolution of the loop, and it will be seen that the pressure increases from zero to a maximum during the first quarter, decreases to zero during the second, then changes in direction. This causes the alternating of the current*

Thus, when the loop is in the horizontal position, the direction of the field also being horizontal, the two sides of the loop will be moving in a path, just for an instant, perpendicular to the direction of the magnetic field, and the rapidity with which the two sides of the loop are cutting the lines of force is greatest, hence the induced electrical pressure in the loop is zero for this position of the loop. The value of the induced electrical pressure for positions intermediate between those just given will depend upon how fast the sides of the loop are actually moving across the magnetic field.

A curve may be drawn which will show graphically the relation between the induced electrical pressure in the loop and its position with respect to a plane perpendicular to the magnetic field. Draw a line A B, as in Fig. 104, and divide this line into, say, twelve equal parts; each part will then correspond to 30 degrees movement of the coil or loop about its axis. Start with the coil in a plane perpendicular to the magnetic field, and let this correspond to the point A in the figure; the electrical pressure induced in the loop for any movement from this position should be meas-

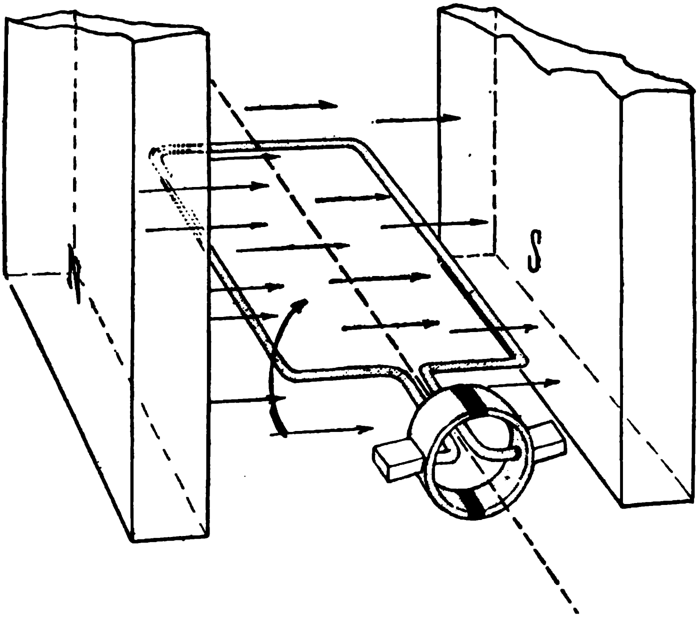


Fig. 105—Simplest direct-current generator—a single loop and a two-segment commutator

ured off to a convenient scale on a perpendicular line drawn through the point on A B, corresponding to the displacement of the loop. Thus, the electrical pressure will be a maximum when the loop has rotated through an angle of 90 degrees. It then decreases as the angle increases from 90 degrees to 180 degrees and becomes equal to zero when the loop has rotated through an angle of 180 degrees. The direction of the movement of the two sides of the loop with respect to the magnetic field changes just as the coil passes the 180-degree position and, as a result, the direction of the induced electrical pressure changes. The numerical values of the reduced pressure for the second 180 degrees are identical to those for the first 180 degrees, but they act around the loop in the opposite direction and are said to be opposite in sign. The difference in the sign is represented in the curve by drawing the second part of the curve below the horizontal line.

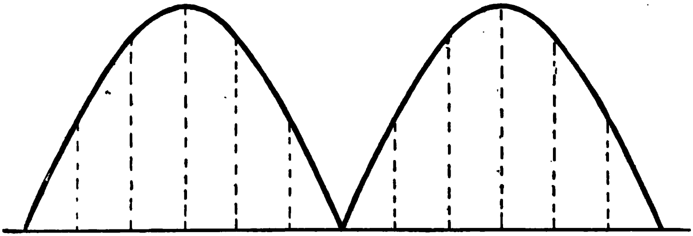


Fig. 106—*Curve showing the variation in electrical pressure produced by a generator with a two-segment commutator. It will be seen that the portion of the curve below the line in Fig.* 104 *is now above the line, and the current all is in the same direction*

Such a curve represents the change in pressure of a simple alternating current generator.

Simple Direct-Current Generator

The electrical pressure induced in the loop of wire described in the previous section may be made to produce a direct current—one that is constant in direction in the external circuit in the following way: Suppose the two continuous metallic rings be replaced by a single ring composed of two parts that are insulated from each other, the distance between the ends of the two parts composing the ring being small in comparison to the total circumference of the combined ring. If the two ends of the loop be connected to these two parts of the ring, which are called segments, and two brushes that are insulated from each other be so mounted with respect to each other that they rest upon the insulation between the segments when the induced electrical pressure in the loop is zero, the connection of the external circuit with respect to the loop will be reversed at the same instant the direction of the induced electrical pressure in the loop changes. This results in the induced electrical pressure in the loop always tending to send a current through the external circuit in the same direction.

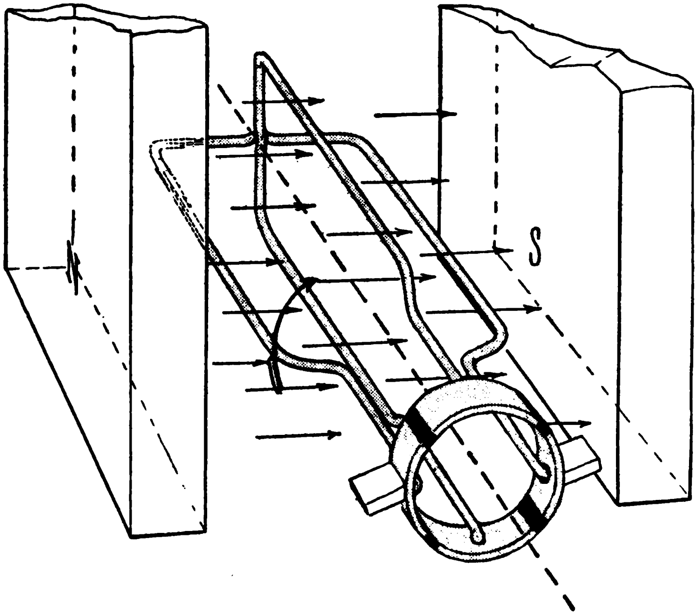


Fig. 107—*A direct-current generator having two loops of wire and four segments in the commutator. This makes the pressure more even as indicated in Fig.* 108. *When one loop is cutting the fewest lines of force, the other is cutting the greatest number*

The proper arrangement of loop, segments and brushes is shown diagrammatically in Fig. 105. Such a machine constitutes a simple direct-current generator, because it delivers a current to the external circuit in one direction. The two-part ring constitutes a simple commutator of two segments and its purpose, as pointed out, is to reverse the connection of the external circuit with respect to armature winding, or vice versa, so that the induced electrical pressure in the winding will send a direct current through the external circuit. A curve showing the variation in the electrical pressure between the two brushes on a two-segment commutator is shown in Fig 106. An electrical pressure such as that represented in Fig. 106 is called a *pulsating* electrical pressure, because it pulsates or changes from zero to a maximum and back to zero at regular intervals, but does not change in direction.

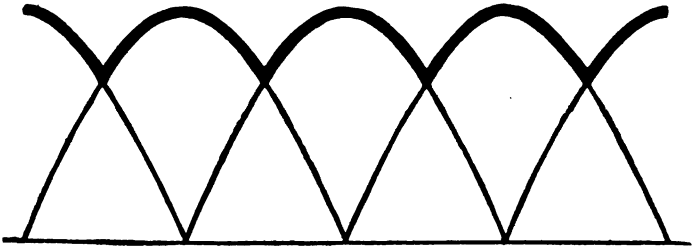


Fig. 108—*Curve showing the variation in electrical pressure between the brushes of a direct-current generator having two loops of wire and four segments in the commutator. When the pressure in one loop is zero, the pressure in the other loop is greatest, so that the pressure is more nearly uniform than is the case with one loop only*

Four-Segment Commutator

If the armature of a direct-current generator were constructed with a single loop of wire composed of one or more turns, the current delivered by such a machine would pulsate in value the same as the induced electrical pressure, as shown in Fig. 106. The operation of such a machine would be very unsatisfactory in a great many cases, especially in charging storage batteries. Fortunately, the electrical pressure between the brushes of the machine can be made to remain more nearly constant in value in the following manner:

Suppose two loops of wire are used instead of one and that the ring is split into four parts instead of two and the brushes placed diametrically opposite each other and in such a position that the insulation passes under them when the loops each make an angle of 45 degrees with the magnetic field. The arrangement of loops, segments and brushes is shown in Fig 107. The induced electrical pressure in the two loops passes through a series of values similar to those represented by the curve in Fig. 104, but the induced pressure in one is greatest when the induced pressure in the other loop is zero. When the brushes are in the position shown in Fig. 107, the electrical pressure between the brushes does not drop to zero value for any position of the two loops, as the brushes are always in contact with segments which in turn are connected to the ends of a loop in which there is an induced electrical pressure. The two loops are alternately connected to the two brushes and each remains in circuit for one-fourth of a complete revolution each time. Each coil is connected and disconnected twice during each revolution. The pressure between the brushes for such an arrangement of coils, segments and brushes as that shown in Fig. 107 is shown by the shaded portion of the curves in Fig. 108.

The induced electrical pressure can be made more nearly constant by using more loops and more segments and placing them in such a position with respect to the first ones that the induced electrical pressure in the loops does not reach a zero maximum value at the same time it does in the others, and connecting them in such a way that the induced electrical pressure in all of the loops acts in series, parallel or series-parallel practically all of the time.

Simple Ring Armature

The operation of the generator having two loops of wire and four segments in the commutator, as shown in Fig. 107, is not altogether satisfactory, as each loop is connected to the external circuit only while the brushes are in contact with the segments of the commutator, to which the terminals of the loop are connected. An armature winding of this type is called an *open-circuit winding.*

A better form of winding for direct-current dynamos, called a *closed-circuit winding,* makes use of all of the loops of wire all of the time except when the two commutator segments to which a loop is connected are in contact with a brush or brushes of the same polarity. One of the simplest forms of closed-circuit winding is shown in Fig. 109, which consists of a wire ring with four coils wound about it and interconnected by means of four commutator segments as shown in the figure. For convenience in referring to these coils they are designated as A, B, C and D. The two coils

A and B are short-circuited by the two brushes when they are in the position shown in the figure. An instant later, however, coil A is in series with coil B on the right side and coil C is in series with coil D on the left side, and this connection remains until coils B and D are short-circuited by the brushes. An instant later, coil D is in series with coil A on the right side and coil B is in series with coil C on the left side.

It is apparent that the coils opposite each other are short-circuited by the brushes at the same time when they are symmetrically arranged, as in this case, and as one coil leaves the right circuit and enters the left circuit at the lower brush, while there is a coil leaving the left circuit and entering the right circuit at the upper brush. With this arrangement of commutator segments and coils, all of the coils are in circuit with the external circuit all of the time, except when they are short-circuited by the brushes. If the position of the brushes on the commutator is such that the coils are moving parallel to the magnetic field when the coils are short-circuited, there will be no electrical pressure induced in the coils and, as a result, the electrical pressure between the brushes is not decreased by short-circuiting the coils.

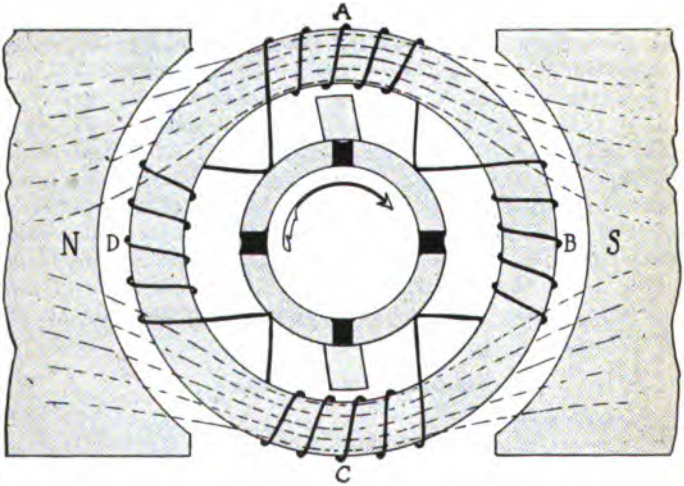


Fig. 109—*A four-coil ring armature with a four-segment commutator*

The electrical pressure in all of the coils on the right side of a vertical line through the brushes will be in the opposite direction to the electrical pressure in the coils on the left side of the vertical line through the brushes. The electrical pressures in the coils on the right and left sides of the vertical line act oppositely to each other, just as the electrical pressures of two batteries connected in parallel act opposite with respect to each other, but they act in the same direction with respect to the external circuit.

The movement of the coils across the magnetic field just before they are short-circuited is in the opposite direction to their movement across the magnetic field after they have been short-circuited. This results in the electrical pressure induced in the coils before they are short-circuited acting around the coil in the opposite direction to that in which the electrical pressure induced in the coil after it has been short-circuited acts. In other words, the electrical pressure induced in the coil reverses in direction while the coil is short-circuited.

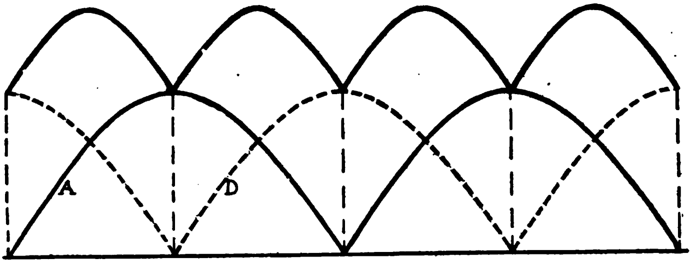


Fig. 110—Curve showing variation of electrical pressure between the terminals of a four-coil ring armature with a four-segment commutator

The total electrical pressure between the brushes at any instant will be equal to the sum of the electrical pressures induced in the coils connected in series between the brushes. When the coils are symmetrically placed, as shown in Fig. 109, the variation in the electrical pressure between the brushes will correspond to the variation in the total pressure of the coils connected in series between the brushes. Thus the electrical pressure induced in the coil A with respect to the external circuit may be represented by a curve similar to the one marked A in Fig. 110. Both parts of the curve are drawn above the horizontal line, as the connection of the coil with respect to the external circuit changes when the coil passes the position of short-circuit or the position where the induced electrical pressure reverses in direction. The electrical pressure induced in the coil D with respect to the external circuit may be represented by a second curve D. The electrical pressure in A is a maximum when the electrical pressure in D is zero and the electrical pressure in D is a maximum when the electrical pressure in A is zero. The electrical pressure between the brushes at any instant will be equal to the sum of the pressures induced in the two coils connected in series at that instant, and it may be represented by a third curve whose height above the horizontal is equal to the sum of the height of the two curves A and D. This third curve is shown heavy. From an inspection of Fig. 110, it is seen that there are four loops to the shaded curve and that the pressure fluctuates in value. By increasing the number of coils on the ring and the segments in the commutator, the number of fluctuations in the pressure between the brushes for one revolution will be increased and the variation in the pressure decreased. A six-coil armature and six-segment commutator are shown in Fig. 111. The electrical pressure between brushes for such a combination of coils is shown by the shaded curve in Fig.

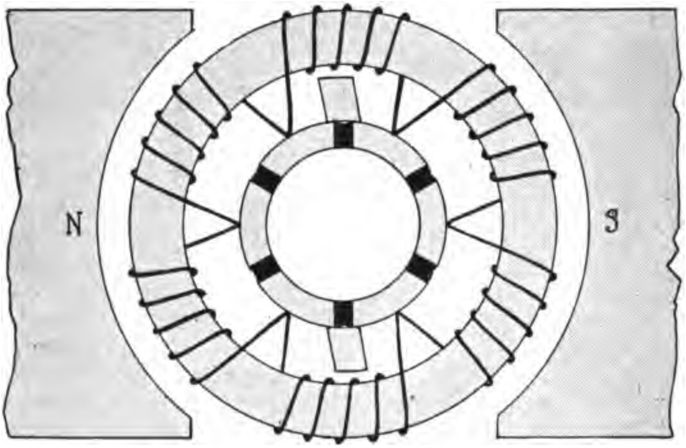


Fig. 111—*A six-coil ring armature with a six-segment commutator*

112. The height of this shaded curve is equal to the sum of the heights of the three other curves.

Multipolar Ring Armature

The armature of a generator may be revolved in a magnetic field of more than two poles, providing the connections of the various coils and the position of the brushes are properly made. For example, a four-pole armature is shown in Fig. 113. Four brushes are used and alternate ones are of the same polarity and connected together. The brushes are shown inside the commutator; they are in reality, however, outside. In passing from the negative terminal of such a winding through the winding to the positive terminal there are four possible paths. If this were a six-pole armature there would be six paths and so on. There are types of windings, however, in which the number of paths through the winding may be greater than the number of magnetic poles forming the magnetic circuit and in some the number of paths may be less than the number of poles. Space will not permit a discussion of these various types, and the reader should make use of a book devoted entirely to armature windings if he cares to investigate the many possible types.

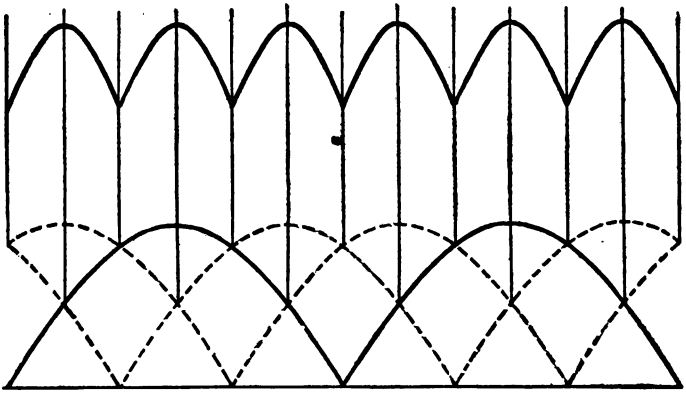


Fig. 112—Curve showing variation in electrical pressure between the terminals of a six-coil ring armature with a six-segment commutator

Simple Drum Armature

In the case of the ring armature, the wire forming the winding is wound on a wire ring, while in the *drum* armature the winding is placed around a cylinder of iron. The drum armature has a decided advantage over the ring armature in that more of the wire used in the winding has an electrical pressure induced in it. In the ring winding the part of each turn of wire inside the ring has practically no electrical pressure induced in it, and as a result only the part of each turn on the outside of the ring is effective in producing an electrical pressure. In the drum winding, both sides of each turn are on the surface of the armature and have an electrical pressure induced in them.

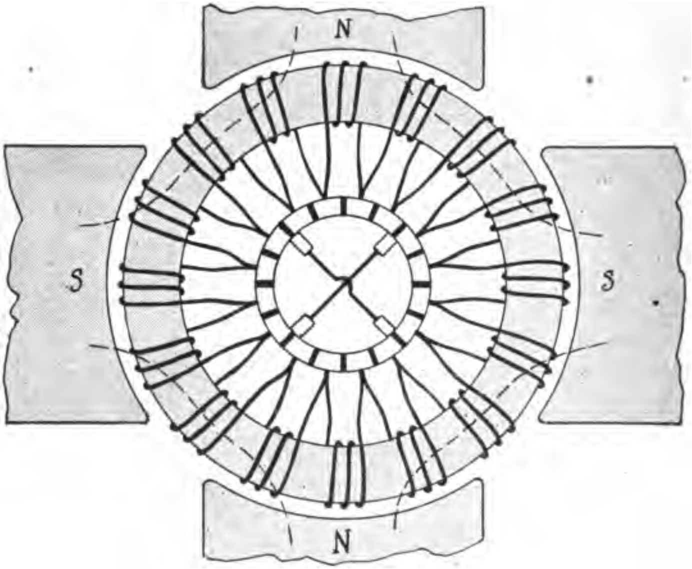


Fig. 113—*A sixteen-coil ring armature operating in a four-pole magnetic field*

That part of an armature winding in which the electrical pressure is induced is called an *inductor* and there will be as many inductors in a ring winding as there are turns, while in a drum winding there will be twice as many inductors as there are turns.

Electrical Pressure Induced in Armature Winding

The electrical pressure induced in an armature winding will depend upon the rapidity with which the magnetic lines of force are cut by the inductors composing the winding. The magnetic lines of force cut by each inductor in one revolution is equal to the product of the number of magnetic poles forming the magnetic circuit and the magnetic lines of force entering or leaving the armature at each pole.

The number of magnetic lines of force cut by each inductor in one second will be equal to the product of the lines cut per revolution and the number of revolutions per second.

The electrical pressure induced by the armature winding will depend upon the manner in which the inductors forming the winding are connected, that is, whether there are two circuits through the winding, four circuits, etc. The number of inductors in series in each circuit is equal to the total number of inductors divided by the number of paths through the winding, and the greater the number of inductors in series the greater the induced electrical pressure, all other things remaining unchanged.

If the lines of magnetic force cut by each inductor in one second be multiplied by the number of inductors in series the product will be equal to the total lines of magnetic force cut by all of the inductors in series in 1 second. This total number of magnetic lines of force cut by all of the inductors in series divided by 100,000,000 gives the electrical pressure in volts, induced in each path of the armature winding.

The only two factors which may be changed after the machine is constructed are the magnetic lines of force per pole and the revolutions of the armature. If the number of magnetic lines per pole remains constant, the induced pressure will vary directly as the speed of the armature. Likewise, if the speed remains constant the induced pressure will vary directly as the number of magnetic lines of force per pole.

It is by varying the speed of the armature or the number of magnetic lines of force that the output of a generator as to voltage is regulated. This will be explained later.

CHAPTER XIII

Fields and Field Windings for Generators and Motors

IN the previous consideration of the production of an electrical pressure, in a conductor when it is moved across a magnetic field, as in the case of the armature of a generator, the presence of the field has been assumed and nothing has been said as to the method of providing the magnetic field. The term "field" is applied interchangeably to the magnetic lines of force between the pole faces of the field magnets and to the field magnets themselves. There are two methods of producing the magnetic field for generators and motors, and these methods will be discussed in the following paragraphs:

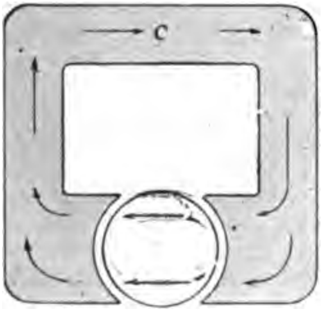


Fig. 114—*Magnetic circuit of simplest bipolar machine with one field coil at C*

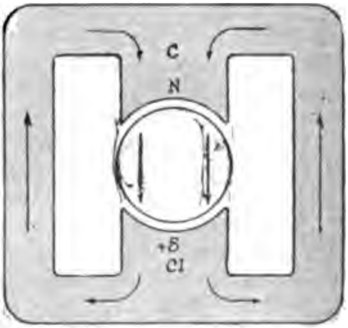


Fig. 115—*Bipolar magnetic circuit with two field coils, one at C and one at C1*

The permanent magnet provides perhaps the simplest method of producing a magnetic field. The field produced by a permanent magnet is quite weak as compared to one produced by an electric current, and the magnetic field of the permanent magnet cannot readily be changed to meet changing requirements. The use of the permanent magnet as a means of producing a magnetic field is confined in motor cars almost entirely to the ignition magneto at the present time.

If an electric current be passed through a winding surrounding a piece of iron, the piece of iron will become magnetized by the action of the current. The degree to which the piece of iron becomes magnetized will depend upon the number of turns of wire in the winding and the current in the winding. The polarity of the pieces of iron will depend upon the direction in which the current passes around it, as previously explained. The magnetic circuit of the generator and the motor is the path in which the magnetic lines of force exist and may assume many different forms, depending upon individual requirements.

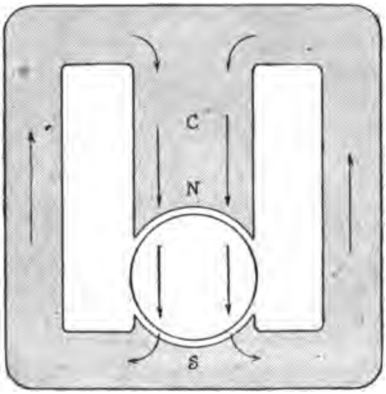


Fig. 116—*A bipolar field with one coil*

Types of Magnetic Fields

The simplest form of magnetic field is one in which the armature rotates between two magnetic poles, and it is known as a bipolar field. Three different forms of bipolar magnetic fields are shown in Figs. 114, 115 and 116. In Fig. 114 the winding in which the current producing the magnetic field flows is placed around the part of the magnetic circuit marked C in the figure. This winding is always spoken of as a field winding. The magnetic lines produced by the current in this winding circulate in the magnetic circuit indicated by the arrows, and they are all produced by a single coil of wire. This coil of wire is usually spoken of as a field coil.

A bipolar magnetic field is shown in Fig. 115. There are two field coils, one about C and another about C1. Both of these field coils tend to produce a magnetic field through the armature in the same direction. There are two paths for magnetic lines around the outside.

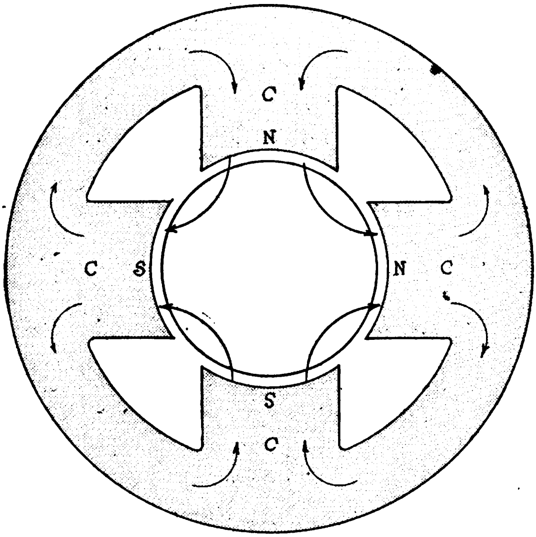


Fig. 117—*A four-pole magnetic circuit with four field coils*

A third type of bipolar magnetic field is shown in Fig. 116. In this case there is only one field coil, and it is placed around the part marked C. There are two paths for the magnetic lines around the outside, similar to the circuits shown in Fig. 115.

A multipolar magnetic circuit of four poles is shown in Fig. 117. In this case there are four field coils and they are wound around the four parts marked C. It will be seen that two of these field coils act on any one of the four magnetic circuits. Alternate poles around the armature are of the same polarity, and adjacent poles are of opposite polarity.

A four-pole magnetic circuit is shown in Fig. 118, but only two field coils are used instead of four, as in Fig. 117. These two field coils are placed about the parts of the magnetic circuit marked C in the figure. The general appearance of the magnetic circuit, as shown in Fig. 118, is quite similar to the one shown in Fig. 115, which is bipolar. A close comparison of the two will make the difference very noticeable. In Fig. 115 field coils about C and C1 both act to produce a magnetic field through the armature in the same direction, while in Fig. 118 the two field coils act to produce the magnetic field through the armature in opposite directions. As a result of the two field coils acting to produce a magnetic field across the armature in opposite directions and on account of the nearness of the iron to the two sides of the armature, the magnetic lines pass through the paths indicated by the arrows. In this case only one field coil acts on any one of the four magnetic circuits.

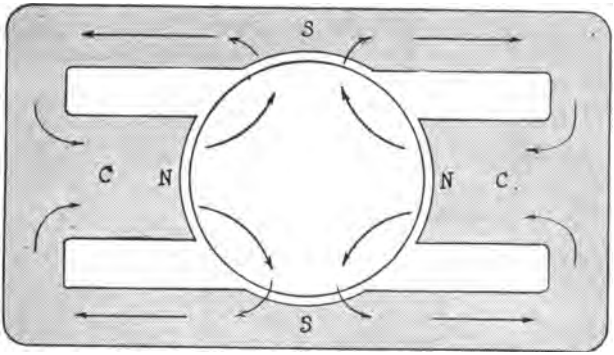


Fig. 118—*A four-pole magnetic circuit with two field coils*

When the magnetic circuit is arranged similarly to Figs. 115, 116, 117, 118 and so forth so that the field winding is practically surrounded by the iron, forming part of the magnetic circuit, it is called an iron-clad type. This type of construction is a better protection for the field coils, and for this reason, all other things being equal, is much preferred to an open or exposed type of construction, as shown in Fig. 114.

Parts of the Magnetic Circuit

The magnetic circuit of almost every dynamo is composed of five parts, and they are:

First, the armature core, which usually consists of a cylinder of laminated iron, mounted on a shaft and having its surface grooved to accommodate the armature winding. In the ring type of armature the core is in the form of a ring. The reason for laminating the armature core is to produce the loss due to currents in the iron core itself which are called *eddy currents* and which tend to heat the armature and decrease the efficiency of the machine. The armature core serves the double purpose of conducting the magnetic lines from pole to pole and at the same time supporting the armature winding.

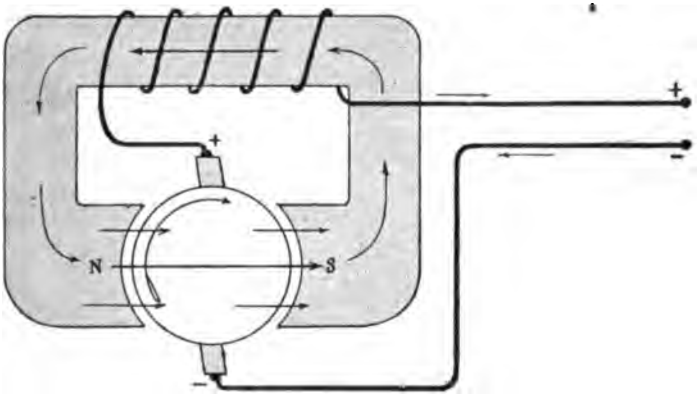


Fig. 119—*A series field winding; the field winding is in the same circuit as the armature and outside circuit*

Second, the air gap, which is the clearance between the armature core and the end of the poles.

Third, the pole shoes, or pole pieces, which are the ends of the poles adjacent to the air gap. They are in some cases given a special shape in order to improve the distribution and arrangement of the magnetic lines forming the magnetic field. In some cases the pole shoes are made separate from the field core and bolted to the cores.

Fourth, the field cores which are the parts of the magnetic circuit about which the field windings are placed.

Fifth, the yoke, which is the outside portion of the magnetic circuit connecting the field cores. The yoke forms part of the magnetic circuit and at the same time serves as a mechanical support for the field cores and pole shoes, holding the pole shoes in their proper position with respect to the armature.

Series Generator

A series generator is one in which the armature and field windings are connected in series, and any current supplied by the armature passes through the field winding. The connections of a series generator are shown in Figure 119. The operation of such a machine, in brief, is as follows: Assuming that there is some residual magnetism in the fields due to their having previously been magnetized there will be a low electrical pressure induced in the armature winding when the armature is revolved in this weak magnetic field. This induced electrical pressure will not produce a current unless the terminals of the machine be connected directly together or by means of an external circuit. The current due to this low induced electrical pressure will flow

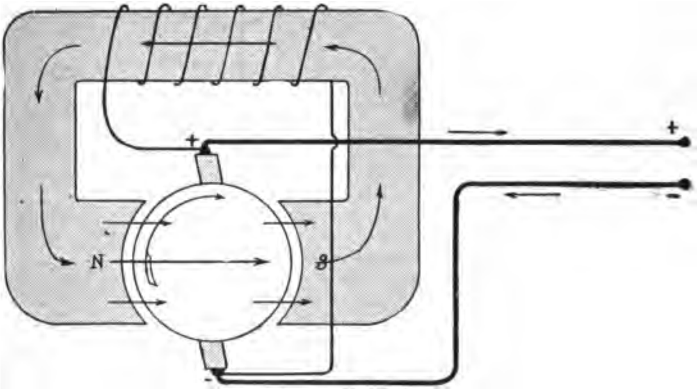


Fig. 120—A shunt field; the field winding is in parallel with the outside circuit

through the field winding and increase the strength of the magnetic field, which in turn will increase the induced electrical pressure, which will increase the current, etc. This operation would continue indefinitely and the induced pressure and current would both become dangerously high unless some means were provided for controlling them. As the current in the field winding increases, the number of magnetic lines in the field increases, but after a certain field strength has been reached, the magnetic lines cease to increase, due to a given increase in current, as rapidly as they did at first, and finally there is a very little increase in these lines, due to an increase in the field current, and the iron forming the magnetic circuit is said to be *saturated.* The series field winding is composed of a relatively small number of turns of wire of ample size to safely carry the maximum current the machine is designed to deliver.

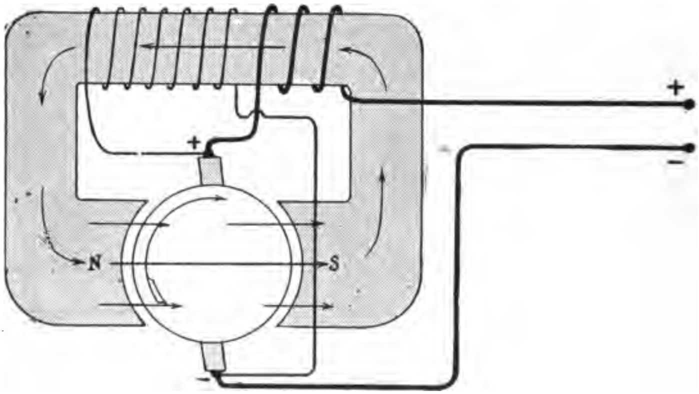


Fig. 121—*A cumulative compound field, in which shunt and series windings are in the same direction*

Shunt Generator

A shunt generator is one in which the field winding is connected directly to the terminals of the armature as shown in Fig. 120. The current in the field winding at any time is equal to the pressure between the brushes divided by the resistance of the winding and is independent of the current the generator may be supplying to a circuit connected to its terminals, unless the current supplied changes the pressure between the brushes. The shunt generator will have a low pressure induced in it's armature, due to the residual magnetism in the fields. This pressure produces a current in the field winding, which in turn increases the strength of the magnetic field. This in turn increases the induced pressure, which increases the field current, etc. This operation continues until the magnetic condition of the iron is such that both the electrical pressure and field current become steady. In the series generator, the terminals of the machine had to be connected together in some way in order that the electrical pressure induced in the armature increase, while in the shunt generator it is not necessary to have the terminals connected in order that the electrical pressure induced in the armature increase. In fact, it is best to have the terminals entirely disconnected from all circuits.

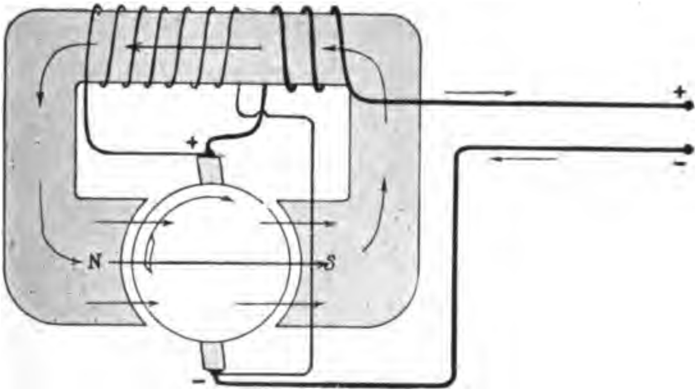


Fig. 122—A differential compound winding in which the shunt and series field coils are wound in opposite directions, and thus buck each other

The shunt field winding is composed of a relatively large number of turns of small wire. The current the shunt field winding carries is usually a small part of the total current the machine is capable of generating.

Compound Generator

A *compound* generator is a combination of a series and a shunt generator. When the magnetizing action of the series and shunt field are in the same direction as shown in Fig. 121, it is called a *cumulative compound* generator. If the magnetizing action of the series and shunt fields are in opposite directions, as shown in Fig. 122, it is called a *differential compound* generator. When the shunt winding is connected directly to the brushes, the machine is called a *short shunt* compound machine, as shown in both Figs. 121 and 122. If the shunt winding is connected across both the armature and series field, the machine is called a *long shunt* compound machine. The action of these field windings will be discussed at length under the subject of generator output. It is by these field windings in some lighting generators that the current to the battery and lights is kept constant.

CHAPTER XIV

Generator Output and Purpose of Cutout

AS explained in the previous section, the electrical pressure generated in the armature winding of a generator depends upon the number of wires on the surface of the armature, the manner in which these wires are interconnected, which determine the number of different circuits through the armature winding; the number of magnetic lines, called the magnetic flux, entering or leaving the armature at the different poles; the number of magnetic poles forming the magnetic circuit; and the speed at which the armature is revolving in the magnetic field. After a generator is constructed, the number of magnetic poles, the number of wires on the surface of the armature and the number of different circuits through the armature are all fixed, while the speed and number of magnetic lines, or magnetic flux, per pole may either or both be changed.

The speed of the generator, of course, depends upon the speed of the device driving it and the manner in which the generator is connected to this device. The armature of the generator may be mounted on the shaft of the driving device or it may be geared or connected to the shaft by a clutch or chain. In some cases the construction of the driving clutch is such that the armature of the generator never exceeds a predetermined speed, regardless of the extent to which the speed of the driving device increases.

The magnetic flux per pole depends upon the form of the magnetic circuits, the kind of material composing the magnetic circuit and the number of ampere-turns acting on each magnetic pole. The number of ampere-turns, magnetizing effect, of a coil is equal to the product of the number of turns in the coil and the current in these turns. After the machine is once constructed, the form of the magnetic circuit, the kind of material composing the magnetic circuit and the number of turns in the different windings about the fields are all fixed and constant in value. The only way then—neglecting armature reaction which will be explained later—that the magnetic flux entering or leaving the armature at the different poles may be changed is by varying the value of the current in the field windings.

Assuming for convenience that the magnetic flux per pole remains constant, then the electrical pressure generated in the armature winding will vary directly as the speed of the armature, starting at nothing for no speed and increasing directly as the speed increases. The relation of the electrical pressure generated to the speed is shown graphically in Fig. 123, in which speed is measured along the horizontal and pressure along the vertical. If the magnetic flux per pole be changed, say decreased, then there will be a corresponding decrease in the pressure generated for the different speeds as indicated by the dotted curve.

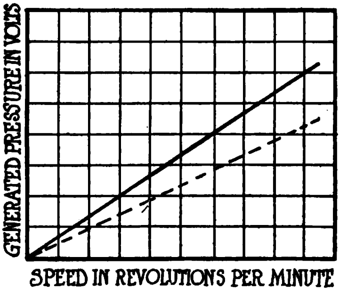


Fig. 123—*Relation between armature speed of a generator and the pressure it generates. The dotted line shows how the pressure drops when the speed decreases and why the lights dim slightly when engine slows*

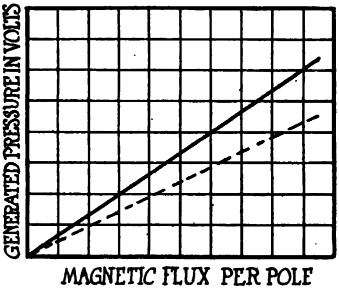


Fig. 124—*Relation between the magnetic flux in a generator and its generated pressure, at constant speed. The dotted line shows how the pressure drops when the field strength decreases*

If the speed of the machine be maintained constant and the magnetic flux per pole be increased, there will be an increase in the electrical pressure in the armature winding as shown graphically in Fig. 124, in which magnetic flux is measured along the horizontal and pressure along the vertical. If the speed of the machine be changed, say decreased, then there will be a corresponding decrease in the pressure generated for the different values of magnetic flux per pole as indicated by the dotted curve.

The magnetic flux per pole does not have a definite relation to the current in the field winding surrounding the pole, due to the fact that the permeability of the iron forming the magnetic circuit is not constant but depends upon the degree to which it is magnetized. You can think of the permeability of the iron as being its property to conduct magnetic flux as compared to the ability of air to conduct magnetic flux, which for convenience is assumed to have a permeability of one. The relation between the magnetic flux per pole and the current in the field winding is shown in Fig. 125. It will be seen from an inspection of this curve that the magnetic flux at first increases very rapidly, due to an increase in the value of the field current, but after the flux has reached a value represented by the point A in the curve the increase due to an increase in field current is decidedly less. When the magnetic flux has reached the value represented by the point A, the magnetic circuit is said to be *saturated* and above this point there is very little increase in flux even though there be a large increase in the field current.

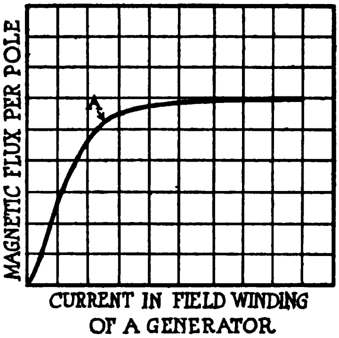


Fig. 125—*How the magnetization of a generator field pole increases with the increase in current in its field winding. The point A indicates the saturation point*

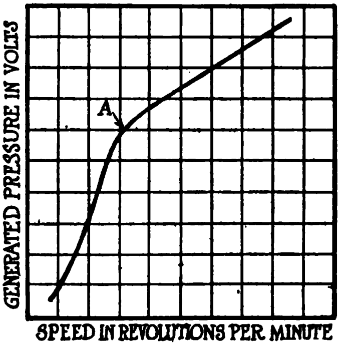


Fig. 126—*Relation between the generated pressure and armature speed of a shunt generator. Above a certain point A the pressure increases more slowly with increase in speed*

Operation of Self-Excited Shunt Generator

The connections of the self-excited shunt generator that is, one supplying its own field current, have been given. When the armature starts to rotate there is one electrical pressure generated in its winding, due to the residual magnetic flux in the magnetic circuit, which produces a current in the field winding and this current increases the magnetic flux per pole. As a result of both the speed and magnetic flux increasing, the generated pressure increases more rapidly than if the speed alone were to increase. After the magnetic flux has reached a certain value, however, the magnetic circuit becomes saturated and then there is very little increase in the magnetic flux per pole even though the field current continues to increase.

After the magnetic circuit has become saturated, the increase in generated pressure is due almost entirely to the increase in speed. The relation between generated pressure and speed is shown in a general way in Fig. 126. Up to the point A on the curve there is a very rapid increase in generated pressure as the speed increases, since the magnetic flux per pole and the speed are both increasing. From the point A, however, the generated pressure increases less rapidly, as the magnetic circuit is practically saturated and the speed above is increasing.

Constant Current and Constant Voltage Output

The output of a generator in watts is equal to the product of the current the generator is delivering in amperes and the pressure at which this current is delivered in volts. The current delivered by a generator to a circuit containing no other source of electrical pressure is equal to the generated pressure in the armature of the generator divided by the total resistance of the circuit, including the connecting leads and the resistance of the armature of the generator itself. If the pressure generated in the armature winding of the generator remains constant, the current supplied by the generator will vary inversely as the resistance of the circuit in which the generator is connected. That is, if the resistance of the circuit increases, the current in the circuit will decrease and if the resistance of the circuit decreases, the current will increase.

If the pressure generated in the armature winding of the generator changes in value, the resistance of the circuit remaining constant, there will be a corresponding change in the value of the current. That is, if the pressure increases, the current will increase and if the pressure decreases, the current will decrease. If, however, the pressure generated in the armature of the generator and the resistance of the circuit both changes, then the current at any time is equal to the pressure at that time divided by the value of the resistance at that time.

When the output of a generator is at a practically constant current, the pressure varying in value or not as the case may be, the generator is spoken of as a *constant current* generator. When the output is at a practically constant pressure, the current varying in value or not as the case may be, the generator is spoken of as a *constant pressure* generator.

Purpose of the Cutout

The electrical generator in its application to the motor car is almost always used in combination with a storage battery. The generator is used to charge the battery and to produce a current in the various electrical devices on the car while the generator is in operation. The battery serves as a sort of reservoir in which electrical energy may be stored and then used when the generator itself is not operating. A battery and generator are shown connected in series in Fig. 127. The positive terminal of the generator is connected to the positive terminal of the batteries and their negative terminals are connected together. The effective pressure acting in such a circuit is equal to the difference in the pressure produced by the generator and the pressure produced within the battery.

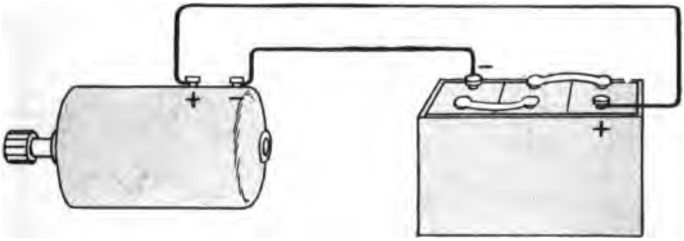


Fig. 127—*Simplest connection of generator and storage battery. When generator is not supplying current, the storage battery discharges through it*

If these two pressures are equal, the value of the effective pressure will be zero and there will be no current in the circuit. If the pressure produced by the generator exceeds in value the pressure produced by the battery, there will be an effective pressure acting in the circuit and its direction will correspond to that of the larger pressure, or the pressure of the generator. The current produced by this effective pressure will charge the battery, and the value of the current will be equal to the effective pressure divided by the total resistance of the circuit, including the internal resistance of the battery, the resistance of the connecting wires and the resistance of the armature winding of the generator.

If the pressure generated in the armature winding of the generator is less than the pressure of the battery, then the effective pressure will be in the direction of the battery pressure and the battery will discharge instead of being charged. The value of the current will, as in the previous case, be equal to the effective pressure divided by the total resistance of the circuit.

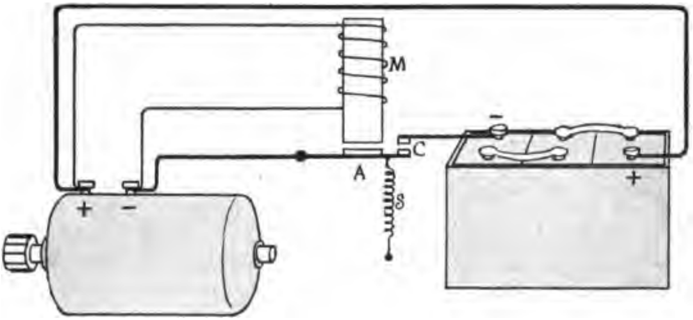


Fig. 128—*A simple form of magnetic cutout. The circuit is broken at C whenever the generator is not developing sufficient current to magnetize M and draw A up to it*

Since the pressure generated in the armature winding of the generator may vary in value from zero on up, depending upon its speed and field control, it is apparent that some means must be provided for controlling the connection between the generator and the battery in order that the battery will not be allowed to discharge through the generator when the pressure of the generator becomes lower than the pressure of the battery. The object of the cutout may be understood by use of the simple diagram given in Fig. 128. An electromagnet M has a winding of a large number of turns, and this winding is connected directly to the terminals of the generator. The resistance of the winding of this electromagnet is usually such that a very small current passes through it in comparison to the total current output of the generator. An armature A carried on a spring pivoted at its left-hand end and carrying a contact point on its right-hand end is mounted near the core of the electromagnet.

This armature is usually held away from the core of the electromagnet by means of the springs, and the movable contact point C is not in contact with the stationary contact point. The connections of the generator and battery are clearly indicated in the figure. Now as the pressure generated in the armature of the generator increases there will be an increase in the current in the winding of the electromagnet M, and the tension of the spring S may be so adjusted that the armature A pulls up the desired value. The tension in the spring S is usually so adjusted that the generator pressure is a little higher than the battery pressure when the circuit is completed, and the battery will always start to charge. When the pressure of the generator decreases, due to any cause, there is a decrease in the current in the winding of the electromagnet M and the magnet pull it produces on the armature A decreases in value. If the pull of the spring S exceeds the magnetic pull the armature will move away from the core of the electromagnet and the circuit between the battery and generator will be broken at the contact C.

The cutout whose connections and arrangement are shown in Fig. 128 would be satisfactory for closing the electrical circuit connecting the generator and battery, but would not open it properly in practice for the following reasons: In theory the spring S would pull the armature away from the core of the electromagnet when the electrical pressure generated in the armature of the generator dropped below a value which would produce the necessary current in the winding to hold the armature up. The following action, however, takes place in actual practice: When the electrical pressure of the generator exceeds the electrical pressure of the battery, the direction of the current in the battery, generator and winding of the electromagnet will be as indicated by the three arrows in Fig. 129. If there is a decrease in the electrical pressure of the generator, due to any cause, or an increase in the electrical pressure of the battery and the two pressures become equal in value, there will be no current in the circuit composed of the generator and the battery.

If the winding of the cutout be connected when the pressures of the generator and battery are equal, a current will be established in the winding, which will be supplied jointly by the generator and battery, and the direction of the currents will be as indicated in Fig. 130. The division of the total current supplied the cutout between the generator and the battery will depend upon the relation betwen their internal resistances. When the electrical pressures within the generator and the battery are each exactly the same and their internal resistances are equal, then each of them will supply one-half of the total current in the winding of the cutout. If their internal resistances are not equal, their pressures being equal, then the one having the smaller internal resistance will supply the larger part of the total current in the winding of the cutout.

When the electrical pressure in the armature winding of the generator is less than the electrical pressure in the battery, then the battery starts to discharge and sends a current through the armature of the generator in the opposite direction to the pressure generated in the armature, as indicated in Fig. 131, thus causing a motor action to take place. The degree of this motor action will depend upon how much current is produced in the armature winding, which in turn will depend upon the difference in the pressure in the armature of the generator and the pressure of the battery, or the effective pressure, divided by the total resistance of the entire circuit. It is interesting to note that the battery will supply a current to the winding of the cutout and that the direction of this current in the winding of the cutout is the same as when it was supplied by the generator. This results in the armature of the cutout remaining drawn up, and the circuit

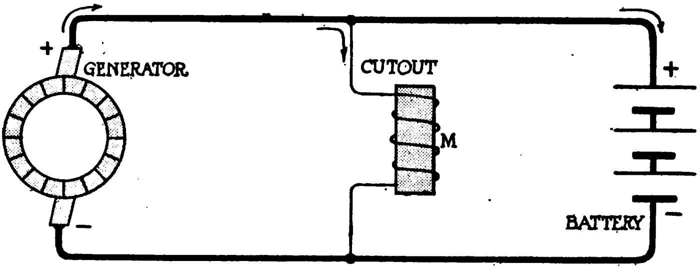


Fig. 129—Direction of currents when battery is charging. The electrical pressure of the generator exceeds that of the battery

between the generator and the battery will remain closed even though the battery is discharging through the armature of the generator. The cutout will remain closed at the comparatively low pressure of the battery when almost discharged, on account of the fact that it does not take as much of a current to hold the armature in place after it is once drawn up as it does to draw it up in the first place, when there is quite an air gap between it and the core of the electromagnet.

The connections outlined in Fig. 132 are used in order to overcome the fault just pointed out. The cutout is provided with two windings instead of a single winding. One of these windings, M, called the shunt winding, is connected directly to the terminals of the dynamo, or rather the two leads from the dynamo, and the current in this winding will be equal to the pressure between the two main line wires divided by the resistance of the winding. The other winding, called the series winding, is composed of a smaller number of turns than the shunt winding and the wire used in this winding is usually quite a bit larger than the wire used in the shunt winding. The series winding is connected directly in the circuit connecting the generator and battery and carries whatever current passes through the battery. The connection of the series winding is such that the direction of the current through it is around the core of the electromagnet in the same direction as the current in the shunt winding when the battery is charging. When the pressure of the generator has built up to the proper value the shunt winding draws up the armature and the battery starts to charge.

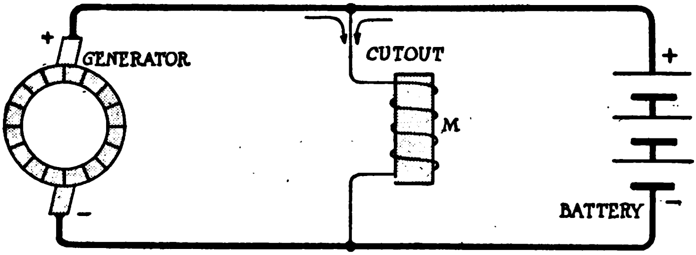


Fig. 130—When the electrical pressures of the generator and the battery are equal, the current to the cutout will be supplied by both, the difference depending on their internal resistances

Let us now consider what happens when the pressure of the generator drops below the pressure of the battery. Just as soon as the generator pressure becomes less than the battery pressure, the battery will start to discharge and the current in the series coil will be reversed in direction. The current in the shunt coil will, however, remain in the same direction as previously explained, which results in the magnetic action of the two coils being opposed to each other. Now, as the pressure of the generator decreases, there will be an increase in the discharge current from the battery and the magnetic action of the series coil will increase. Since the magnetic action of the series and shunt coils are opposed to each other when the battery is discharging, the difference in their effects or the resultant magnetic action acting on the core of the electromagnet will decrease in value as the current in the series coil increases in value. The resultant magnetizing action of the two coils will be zero when the product of the number of turns and the current these turns contain is the same for both coils. The action of the spring S, however, draws the armature away from the core when the resultant magnetic action has been reduced to a certain predetermined value and the circuit connecting the generator and the battery is broken. In order that the circuit be closed again it is necessary that the pressure of the generator increase in value until ample current is produced in the shunt winding to draw up the armature.

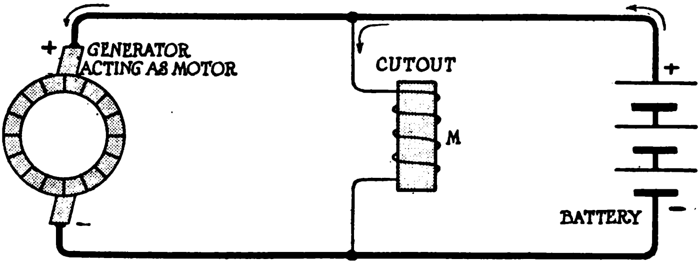


Fig. 131—Direction of current when the battery is discharging. The pressure of the generator has dropped below that of the battery

The series coil performs another useful purpose, in addition to the above, in the satisfactory operation of the cutout. If a cutout having only a shunt coil were made, there would be a tendency for the cutout to open and close at something like the same value of generated pressure. If the car were driven at a speed such that the generated pressure would result in the cutout opening and closing continuously, due to a more or less balanced relation between the magnetic and spring pull on the armature, the contacts would be seriously injured, due to the hammer action at the contacts and also due to excessive sparking. The series coil prevents this occurring in the following manner; the shunt coil acts alone in closing the cutout, as there is no current in the series coil until the cutout contact is closed and the magnetic pull of the shunt coil is just sufficient to overcome the spring pull on the armature when the armature is drawn up. As soon as the circuit is closed, assuming the adjustment is properly made, the series coil will assist the shunt coil in holding the armature. If the electrical pressure now decreases in value, the cutout contacts will remain closed until the combined magnetic action of the shunt and series coils are equal to or a little less than the magnetic action of the shunt coil alone at the time the contacts were first closed. In practice the difference in car speeds at the time of closing and opening of the cutout contacts is something like 2 miles per hour, the speed at which they open being less than the speed at which they close.

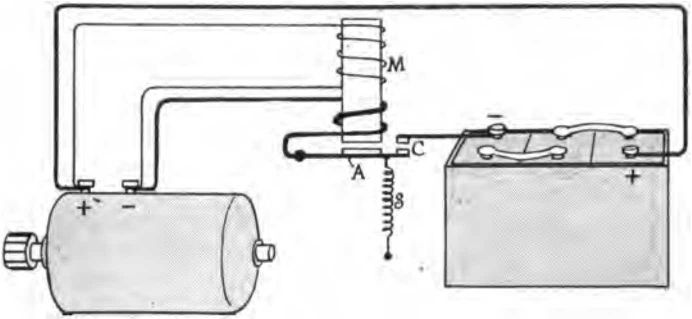


Fig. 132—Complete electromagnetic cutout. The two windings tend to equalize the pressure at the time of the opening and closing of the cutout

Two-Pole Cutout

The cutouts described thus far have only one set of contacts and hence open only one side of the charging circuit. Such cutouts are called single-pole cutouts. In some cases the construction of the cutout is such that both sides of the charging circuit are opened switch. It is customary to attach the ignition switch to the starting switch when this type of cutout is used, and for this reason it might be said that a manually operated cutout will always be interconnected with the ignition switch in such a manner that the circuit connecting the generator and battery will be closed when the ignition circuit is closed and opened when the ignition circuit is opened. A diagrammatic representation of a system of this kind is shown in Fig. 134. The switch in this case is composed of a curved blade B provided with a handle H and pivoted at the point O. The position of the handle shown in the figure corresponds to an idle engine. The two contacts marked C_1 and C_2 are for the purpose of grounding the magnets and thus cutting off the ignition. The dynamo in this case operates as a motor when the main switch is closed, the shunt and series fields acting upon the magnetic circuit in the same direction. As the machine speeds up, the pressure in its armature will increase, and when it exceeds the pressure of the battery, the battery will start to charge. When the battery is charging, the shunt and series magnetic fields act on the magnetic circuit of the dynamo in the opposite direction with respect to each other. The switch may be placed in a position between the two extreme positions, which results in the ignition being operative but the battery entirely disconnected. The shunt field is also opened, which prevents there being a pressure generated in the armature of the generator. Rotary switches may be used instead of the knife type shown in the figure. The principles involved in the manual cutout have been used with Westinghouse, Bijur, Delco, Dyneto and Entz equipment.

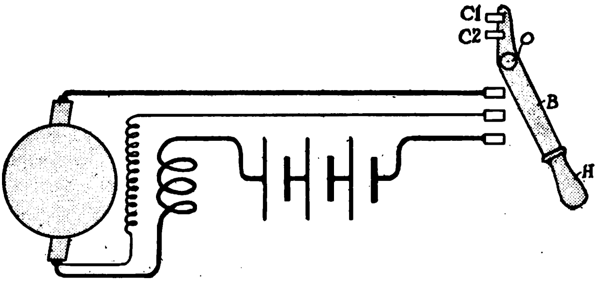


Fig. 134—*Manual cutout showing position of switch, H, when the engine is idle*

CHAPTER XV

Regulation of Generator Output

As previously explained, the output of a generator in watts is equal to the product of the current in amperes the generator is delivering and the pressure in volts between the terminals of the machine. Either the current or pressure may vary in value, the other remaining practically constant, or both may vary in value. In the majority of cases, however, an attempt is made to maintain either the pressure, frequently called the voltage, or the current practically constant in value, thus giving two main types of systems known as the *constant-voltage* and *constant-current* systems, respectively.

There are four different methods of regulating the output of a generator and they may be classified as follows:

(a) *Inherent Regulation.* This type of regulation is that obtained as a result of the characteristics of the generator without the use of any moving parts. In this class are included cumulative and differential series field windings and a type of generator having one or more brushes in addition to those required in delivering a current to the battery and known as a *third-brush* machine. The field current for the shunt winding is taken from this third brush and one of the main brushes.

(b) *Electromagnetic Regulation.* This type of regulation is produced by the action of electromagnets which may act to increase the resistance of the shunt field circuit or to open the field circuit or to change the connections of the field windings.

(c) *Mechanical Regulation.* This type of regulation is produced by the action of centrifugally operated governors which may act to prevent the speed of the generator increasing above a certain definite value or to insert a resistance in series with the field winding or in series with the generator and the battery.

(d) *Regulation by Ampere-Hour Meter.* This type of regulation is produced by means of an ampere-hour meter, which changes the resistance of the field circuit, depending upon the number of ampere hours that may pass into or out of the storage battery.

All the above types of regulation are found in many different applications and in combination with each other, giving rise to numerous distinctive types as used by the different manufacturers of motor car generators.

Cumulative Action of Series and Shunt Field Windings

When the magnetizing action of the current in the series and shunt field windings of a generator are both in the same direction, the action is said to be *cumulative,* and the generator is called a *cumulative* compound-wound machine. A compound-wound machine of this kind is used in combination with a constant-speed machine. A good example of such a combination is found in some of the older types of equipment manufactured by Gray & Davis, in which the generators were driven at a constant speed by means of a centrifugal clutch.

A diagrammatic scheme of connections for this type of regulation is shown in Figure 135. When there are no lamps lighted, the shunt winding is acting alone and sufficient pressure is generated in the armature winding to overcome the pressure of the battery and produce a charging current. When the lamps are turned on, the current through them passes through the series field and increases the magnetic field in which the armature is rotating, thus increasing the electrical pressure generated. By a proper adjustment of the turns in the series field in relation to the current taken by the lamps, it is possible to cause the generator to carry the lamp load and to continue to charge the battery at the same rate it was charging the battery before the lamps were turned on.

Differential Action of Series and Shunt Field Windings

When the magnetizing action of the current in the series and shunt field windings of a generator are in opposite directions, the action is said to be *differential,* and the generator is called a *differential* compound-wound machine. A good example of inherent regulation in which the shunt and series fields produce opposing magnetizing effects is found in one type of equipment made by the Auto-Lite Co. A diagrammatic scheme of connections for this type of regulation is shown in Figure 136. The action in brief is as follows: The voltage of the machine is built up with an increase in speed and shunt field current until the cutout connects the generator to the battery. After this connection is made, a current will be established in the series field winding in such a direction that its magnetizing action is opposite to that produced by the shunt field, and hence the magnetic field is weakened. With a further increase in speed there will be an increase in generated pressure in the armature of the generator, which will cause an increase in the value of the current produced in the series winding and battery and also an increase in the current in the shunt field winding. Since the magnetizing action of the series field is opposed to the magnetizing action of the shunt field, the increase in generated pressure due to an increase in speed will not be as great when both fields are acting as when the shunt field is acting alone. In this case all the current supplied by the dynamo passes through the series field winding.

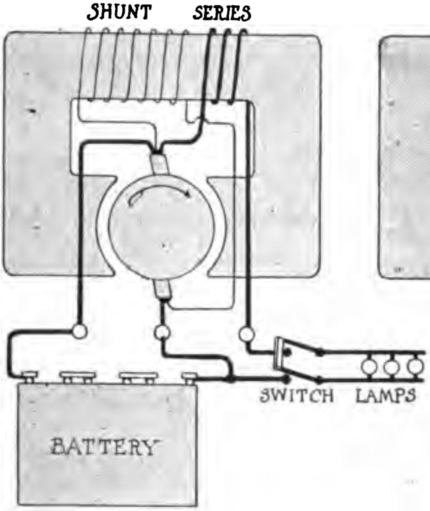


Fig. 135—*Regulation produced by cumulative action of series and shunt fields. The series field carries only the current supplied to the lamps*

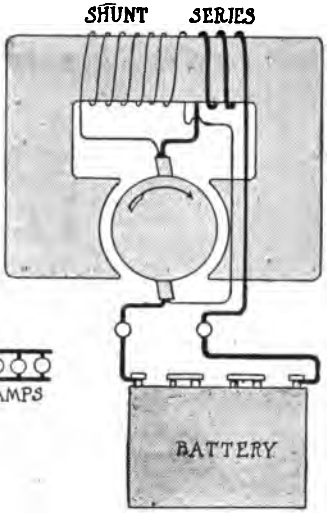


Fig. 136—*Regulation produced by differential action of series and shunt fields. The series field carries the total current supplied by the generator*

Bucking Series Field Winding

The bucking series field winding is really a differential or reversed series field winding, the only difference being that the series field winding does not carry all or necessarily a definite part of the current delivered by the generator. The operation of the bucking coil may be explained by reference to Fig. 137, which is exactly the same as Fig. 136 with a coil of iron wire W connected in parallel with the series field winding. The resistance of iron wire increases with an increase in temperature and this increase is very rapid after a certain temperature has been reached. Now, when the current delivered by the generator is small practically all the current passes through the coil W, as its resistance is much less than the resistance of the series field winding. As the current delivered by the generator increases, the temperature of the iron wire will increase. Hence, there is an increase in the resistance it offers, and as a result, a larger part of the total current delivered by the generator will pass through the series field winding. This increase in current in the series field prevents as large an increase in generated voltage as would occur if no series field were used. When the current supplied by the generator is reduced, the temperature of the iron wire is lowered and the division of the total current between the series field and coil W is restored to its previous value. This system of regulation is used on some of the equipment of the Bosch Magneto Co.; also on the equipment of the Rushmore Dynamo Works, which is now a part of the Bosch Magneto Co.

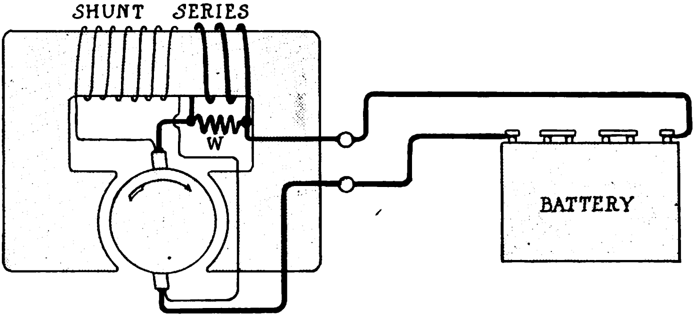


Fig. 137—Regulation produced by bucking-coil. A coil whose resistance changes with temperature is connected in parallel with the series field, which acts differentially with respect to the shunt field. Here the shunt is shown connected directly across the brushes for simplicity, but in practice the terminal shown here connected to the upper brush is connected to the battery line between the battery and the juncture of the series field and ballast coil. This gives a more even pressure

Third-Brush Machine

In order to understand the operation of the third-brush machine it will be necessary to make a brief study of the magnetizing action of the current in the armature winding of a generator in combination with the magnetizing action of the current in the field windings.

A cross-section through the armature and poles of a two-pole generator is shown in Fig. 138. The wires on the surface of the armature are represented by twenty small circles spaced equal distances apart around the outside of the large circle which is sup-

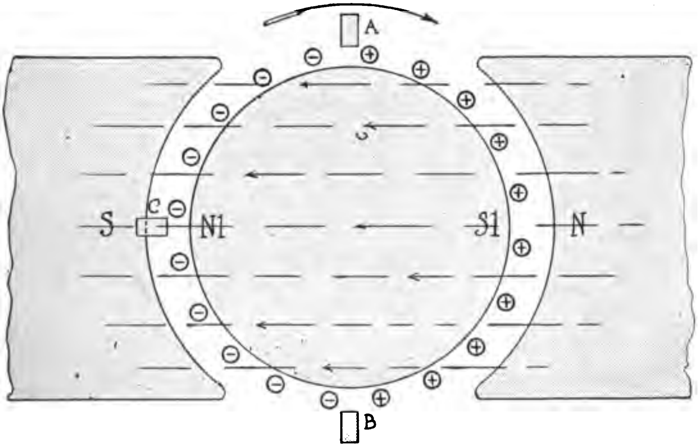


Fig. 138—*Cross-section through fields and armature of a two-pole generator, showing magnetic field produced by the field current alone. If you will think of the + and — signs as being respectively the feathered end and flattened point of an arrow, the diagram becomes plainer*

posed to represent the armature core. As a matter of fact, there are more than twenty wires on the surface of the armature, but this number has been used to simplify the diagram, the results being exactly the same. The polarity of the poles is indicated by N and S; the polarity of the armature core by N and S; and the direction of the magnetic field by the small arrows.

If the armature be revolved in the clock-wise direction, as indicated by the large curved arrow at the top of the figure, an electrical pressure whose direction is away from the observer will be induced in the wires on the left-hand side of a vertical line through the armature, and an electrical pressure whose direction is toward the observer will be induced in the wires on the right-hand side of the armature. An electrical pressure, or current, toward the surface of the paper is represented by a plus (+) sign and one away from the observer by a minus (—) sign. If you will think of the + and — signs as being respectively the feathered end and flattened point of an arrow pointing along the wire, the diagram becomes plain. The direction of the current always can be found by the Right-Hand Rule mentioned previously.

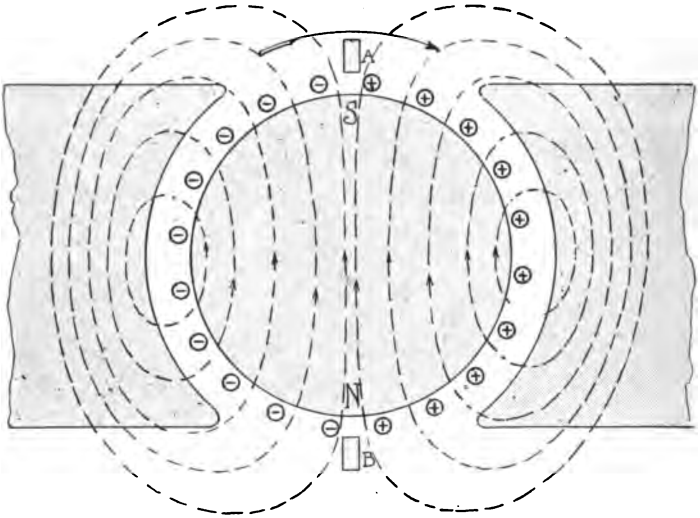


Fig. 139—*Cross-section through fields and armature of a two-pole generator, showing magnetic field produced by armature current alone*

The wires on the surface of the armature are all interconnected by the commutator segments, and a current will be produced in them when the brushes resting on the commutator are connected to a closed electrical circuit. This current in the armature will produce a magnetizing action just the same as the current in the field windings. The magnetic effect of the current in the armature winding of the generator may be investigated by sending a current through the armature from an outside source, such as a battery, in the same direction as the current the generator itself would produce, with the armature standing still and no current in the field windings. The general form of the magnetic field produced by the armature current would correspond to the dotted lines shown in Fig. 139, and its direction through the armature would be from the lower toward the upper side. The polarity of the armature is indicated by N and S in the figure. As a matter of fact, this magnetic field can never exist alone, but the magnetizing effect of the armature current combines with the magnetizing effect of the field current to form a resultant field whose general form will correspond to the one shown in Fig. 140.

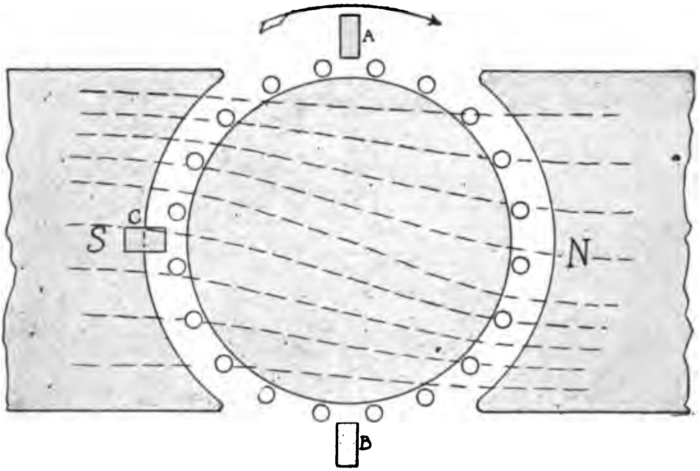


Fig. 140—*Cross-section through fields and armature of a two-pole generator, showing resultant magnetic field produced by armature and field currents acting at the same time*

The magnetizing effects of the armature and field currents may be considered just the same as two mechanical forces which are acting on an object at right angles to each other. Thus the direction of the magnetizing force of the field current may be represented by the line marked F in Fig. 141, and its direction corresponds to the direction in which the arrow head points. Likewise, the magnetizing effect of the armature current may be represented by the line A, and its direction corresponds to the direction in which the arrow head points. The two forces combine to form the resultant force R, which produces the magnetic field whose direction corresponds to the arrow head. The angle the resultant R makes with the horizontal will depend upon the relation between the two forces, A and F, the larger the value of A the greater the angle. This magnetizing action of the armature current is called armature reaction.

If the brushes be placed on the commutator in such a position that they rest on segments that are connected to conductors on the surface of the armature in which there is no induced electrical pressure, a maximum voltage for a given field strength and speed will exist between them. The brushes A and B in Fig. 138 are shown in a position for maximum voltage. If a third brush C be placed on the commutator midway between the brushes A and B, the voltage between A and C will be exactly the same as the voltage between C and B, because the same amount of magnetic flux is cut by the conductors in moving from C to A as is cut in moving from B to C. When the magnetic field is distorted, due to armature

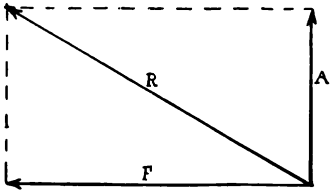


Fig. 141—*The combined magnetizing activities of armature and field currents, A and F form the resultant magnetic activity R*

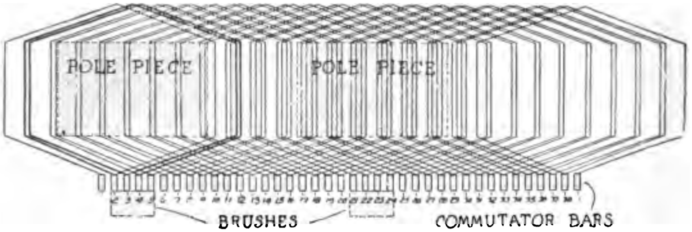


Fig. 142—*Diagram of armature winding on a Delco generator. Each coil is represented by a single turn* reaction, as shown in Fig. 140, the voltage between B and C will be less than the voltage between C and A, since there is a greater amount of magnetic flux cut by the conductors in moving from C to A than is cut by them in moving from B to C.

The position of the brushes shown in Fig. 138, 139 and 140 does not correspond to their actual position in practice, on account of having the end connections of the armature winding all of practically the same length. The armature winding of a Delco generator is shown diagrammatically in Fig. 142. The winding can be imagined as being removed from the surface of the armature and laid out flat with the pole pieces shown shaded. The commutator segments are spread out and shown in their proper relation to the armature conductors. The various coils composing the armature windings are connected together at the commutator segments, and in order that the ends of these coils leading out to the commutator segments be of the same length and form, it is necessary that the segments to which the terminals of a coil are connected be as near the center of the coil as possible. For example, starting with segment number two and tracing through a coil, you end up at segment number three, etc., and segments two and three are placed

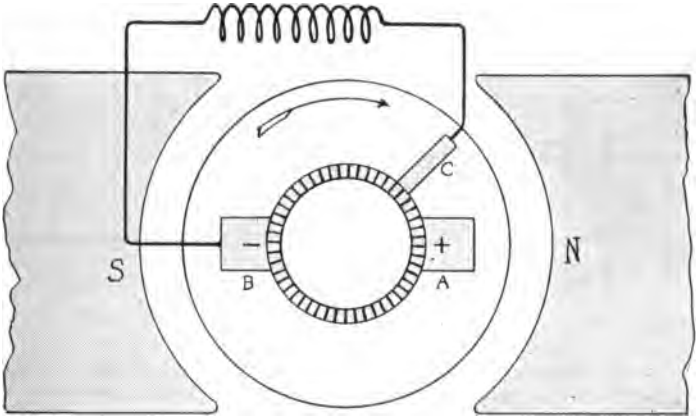


Fig. 143—*Connection of shunt field on third-brush machine. The main brushes are opposite the centers of the poles* opposite the centers of the coils which are shown connected to them in the diagram.

In order to simplify the diagram each coil is represented as being composed of a single turn. With this type of connection the main brushes will be in positions opposite the centers of the poles, as shown in Fig. 142 and 143. The voltage between the brushes B and C will become a smaller and smaller part of the total voltage between the brushes A and B as the magnetic field of the generator is distorted, due to the magnetizing action of the armature current.

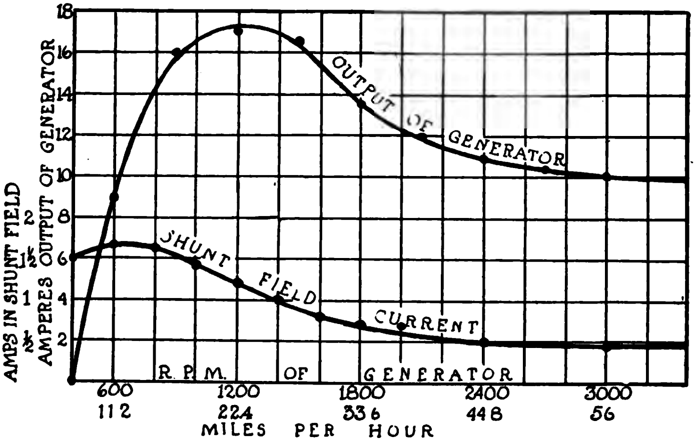


Fig. 144—Curves showing relation of shunt current and delivered current to the speed of car in miles per hour and speed of generator in revolutions per minute for a Delco third-brush generator

The shunt field winding is connected to the brushes B and C, and the current in this winding decreases with an increase in speed of the generator, as shown by the curve marked shunt field current in Fig. 144. The current delivered by the generator increases in value with an increase in speed up to a certain maximum value and then starts to decrease with further increase in speed, due to the weakening of the magnetic field, as shown by the curve in Fig. 144.

Electromagnetic Regulation

Inserting Resistance in Field Circuit Intermittently by Means of a Magnetic Vibrator: The principal of this type of regulation can best be understood by referring to Fig. 145, which shows in a diagrammatic form the electrical connections of the generator, battery and regulator. The regulator consists of an electromagnet with a winding, M, of wire large enough to carry all the current delivered by the generator and connected directly in series with the generator and battery. An armature, A, is mounted near one end of the elctromagnet and normally held away from the core of the electromagnet by means of a spring, S. When the armature moves toward the core of the electromagnet a contact is broken at C. The generator is of the shunt type with one terminal of the field winding connected to one terminal of the machine and the other terminal connected to the remaining terminal of the machine with the contact, C, on the regulator in series. A resistance, R, is connected across the terminals of the contact C and when this contact is opened, due to the action of the electromagnet, the resistance R is in series with the shunt field winding.

The actual operation of the regulator is as follows: As the generator speeds up the electrical pressure between its terminals increases, and when it has reached a value ample to charge the battery the cutout will connect the generator and battery together and the battery will start to charge. With a further inincrease in the electrical pressure between the terminals of the generator, the current delivered to the battery will increase, and unless some means be provided for limiting the value of the pressure of the generator this current will become excessively high and do damage to both the generator and battery. As the current in the winding of the electromagnet increases in value, there is an increase in the magnetic attraction the core of the electromagnet has upon the armature, and when this attraction is sufficient to overcome the action of the spring S the armature will move and break the contact C and introduce the resistance R in series with the field winding. When the resistance R becomes a part of the shunt field circuit, the current in the field winding is reduced in value, which causes a reduction in the strength of the magnetic field in which the armature is revolving and, hence, a reduction in the electrical pressure generated in the armature winding.

This reduction in electrical pressure results in the value of the current supplied to the battery, which passes through the

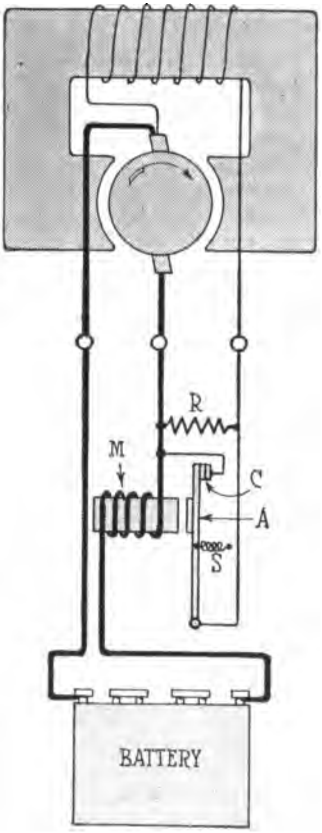


Fig. 145—*Connections of electromagnetic regulator to maintain constant current. The winding M is of large wire and is connected in series with the generator and battery*

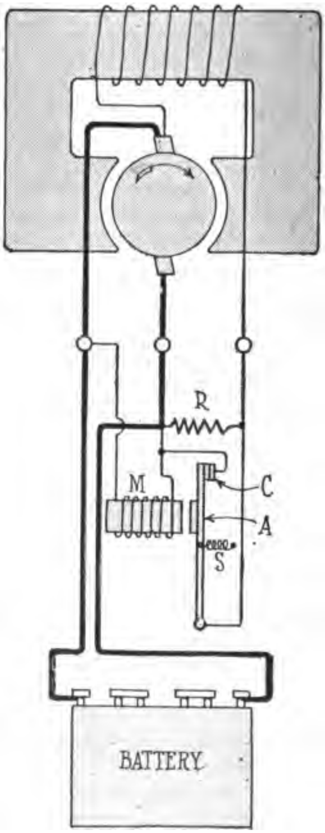


Fig. 146—*Connections of electromagnetic regulator to maintain constant voltage. The winding M has more turns and is connected directly to the terminals of the generator*

winding M, decreasing in value, and the magnetic pull of the core of the electromagnet is no longer sufficient to overcome the pull of the spring S, so the armature moves away from the core and the contact C is closed. The closing of the contact C short-circuits the resistance R, and the field current starts to build up. At the same time the magnetic field in which the armature is revolving increases, which results in an increase in the generated electrical pressure in the armature and, hence, an increase in the current in the winding M. The armature A again is drawn over toward the core of the electromagnet, breaking the contact C and reintroducing the resistance R in the field circuit. This operation is repeated over and over hundreds of times a minute, and the current delivered by the generator, which passes through the winding M, is maintained practically constant at a value depending upon the adjustment of the spring S and the length of the air gap between the armature and the end of the core of the electromagnet. The stronger the spring S and the larger the air gap, the greater the value of the current in the winding M must be in order that the armature be drawn toward the core of the electromagnet and the contact C broken. Likewise, the weaker the spring S and the shorter the air gap, the less current required in the winding M to repeat the above operation.

A slight variation in the winding of the electromagnet and its connections may be made as shown in Fig. 146, when it is desired to maintain a constant voltage at the terminals of the generator rather than a constant current, independent of the speed of the generator armature. The only difference is that the winding M of the electromagnet is composed of a relatively large number of turns of much smaller wire and this winding is connected directly to the terminals of the generator rather than in series with the generator and battery as in Fig. 145. The current in the winding M will increase and decrease with generator voltage, and when the voltage is high enough to produce sufficient current in the winding so that the magnetic pull on the armature A will overcome the action of the spring S, the contact C will be broken and the resistance R introduced in series with the field winding. The action of the resistance R is exactly the same as in Fig. 145, and when the electrical pressure has decreased to such a value that the current it is capable of producing in the winding M does not produce sufficient magnetic pull on the armature to overcome the action of the spring S, the armature will move away from the core and the contact C will be closed, thus short-circuiting the resistance R.

The voltage of the generator builds up again until the magnetic pull due to the current in M overcomes the action of the spring S, etc. This operation is repeated hundreds of times each minute, and the voltage of the generator remains practically constant. The value of the voltage the generator will maintain will depend upon the length of the air gap between the armature and the core of the electromagnet and also the tension on the spring S.

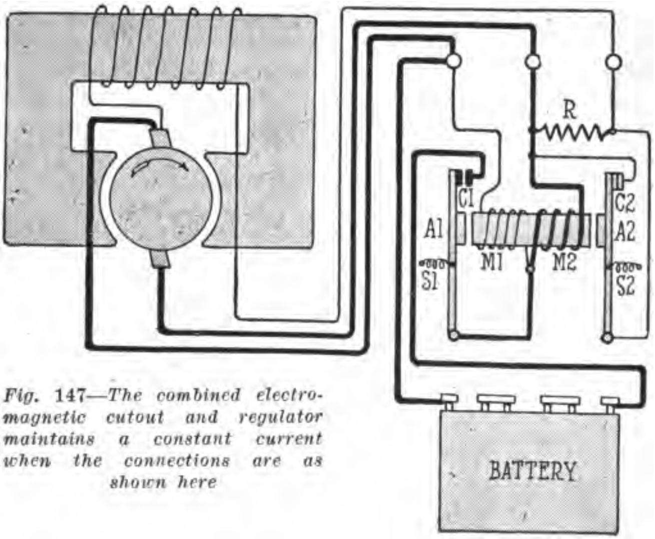


Fig. 147—The combined electromagnetic cutout and regulator maintains a constant current when the connections are as shown here

The greater the length of the air gap and the stronger the tension in the spring the greater the value of the voltage the generator will maintain, as a larger current will be required in the winding M to attract the armature and this larger current will be produced only when the voltage increases, as the resistance of the winding is practically constant. Likewise, a decrease in the length of the air gap and the weaker the spring, the lower the value of the voltage the generator will maintain.

This principle of operation has been used by the Delco, Gray & Davis, North East, Ward Leonard, Remy, Simms-Huff and Allis-Chalmers.

Systems having electromagnetic types of regulators nearly always have an electromagnetic cutout. The two are usually combined in one housing, or containing case, and the combination is spoken of as a controller. In some cases a single electromagnet with two windings will be used, while in some cases two electromagnets will be used, one for the regulator and one for the cut-out. The connection of a controller with a single electromagnet is shown diagrammatically in Fig. 147. The electromagnet is so arranged that the left-hand armature A_1 will be attracted when the current in the winding M_1 produces sufficient magnetic pull on the armatures to overcome the action of the spring S_1. When the armature A_1 is drawn over toward the core of the electromagnet, the contact C_1 is closed and the generator and battery are connected in series, and the generator starts to charge the battery, the current passing through the winding M_2 on the electro-magnet. As the current in the winding M_2 increases, due to any cause, there will be an increase in magnetic pull on the armature A_2, and when this pull is sufficient to overcome the action of the spring S_2 the armature A_2 will be drawn over to the left and the contact C_2 broken. The resistance R causes the current in the field winding to decrease, and, hence, there is a decrease in generated voltage and also a decrease in the value of the current in winding M_2.

When the magnetic action of the currents in windings M_1 and M_2 have decreased to such an extent that the armature A_2 is drawn away by the action of the spring S_2, the resistance R is short-circuited and the voltage starts to build up again, thus increasing the current in the windings. When the voltage decreases below that required to charge the battery, assuming the adjustment of the spring S_1 and the length of the air gap between the armature A_1 and the core of the electromagnet are correct, the magnetic pull due to the current in the winding M_1 is no longer sufficient to overcome the action of the spring S_1 and the contact C_1 is broken, and the generator and battery are no longer connected in series. The magnetic pull required to overcome the action of the spring S_1 is less than that required to overcome the action of the spring S_2, which accounts for the armature A_1 being drawn over before the armature A_2. When the generator is charging the battery, the currents in the windings M_1 and M_2 pass around the core of the electromagnet in the same direction, but if the battery should start to discharge into the generator for any reason the magnetic action of the current in the winding M_2 will oppose the magnetic action in M_1 and the armature A_1 will move away from the core, breaking the contact C_1.

The wiring diagram of the combined regulator and cutout of the Allis-Chalmers Co. is shown in Fig. 148. In this case a single electromagnet with two windings is used. One of these windings, the shunt, serves the purpose of a cutout, while the other, the series, regulates the value of the charging current. When the generator voltage is sufficient to charge the battery, the magnetic action of the current in the shunt winding attracts the armature carrying the cutout contact and the battery starts to charge, the current in the series coil assisting the current in the shunt coil in holding the armature in place. If the charging current increases, due to any cause such as an increase in the speed of the generator, the magnetic pull on the second armature will increase and at some particular value of charging current the second armature will start to vibrate. The vibration of the second armature will cut in and out a resistance in the field of the generator, which will cause a reduction in the charging current by lowering the voltage of the generator.

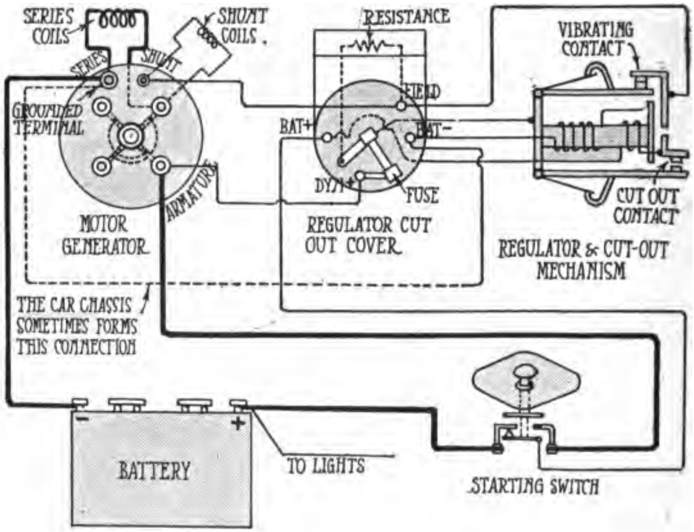


Fig. 148—*Wiring diagram of Allis-Chalmers combined regulator and cutout. A single electromagnet with two windings is used*

Inserting Resistance in Field Circuit Intermittently By Means of a Magnetic Vibrator in Combination With a Load Control: The wiring diagram of the Remy controller shown in Fig. 149 illustrates the use of a magnetic vibrator that is influenced by the lamp load in such a manner that the output of the generator is automatically increased whenever the lamps are lighted and the engine is running at a speed high enough to charge the battery. The cutout has a series winding M_1 and a shunt winding M_2. As the voltage of the machine builds up, the current in the winding M_2 increases until there is sufficient magnetic pull on the armature A_1 to draw it over against the action of the spring S_1 and close the contact C_1. The contact C_1 completes the circuit beween the generator and the battery, and the battery starts to charge, the current passing through the series winding M_2 and the winding M_3 on the second electromagnet. When this current exceeds a certain value the armature A_2 is drawn over by the magnetic pull and the contacts at C_2 are broken and the resistances R_1 and R_2 introduced in series with the field windings. The field current decreases in value, and, hence, the generated voltage which causes a decrease in the value of the charging current increases. As the charging current decreases in value the magnetic pull on the armature A_2 decreases, and finally the spring S_2 pulls the armature away from the core of the electromagnet and the contacts at C_2 are closed. The closing of the contacts at C_2 short-circuits the resistances R_1 and R_2. The voltage of the generator then starts to build up, and the above cycle of operations is repeated many hundred times a minute.

A connection is made to the winding M_3 at the point D, as shown in the figure, and the current for the lamps passes through only a portion of the winding M_3. The current delivered by the generator with the lamps turned on will be greater than when the lamps are turned off, for the following reason: When the lamps are turned on the magnetic pull on the armature A_2 is due to the magnetic action of the charging current going to the battery and passing through the entire winding M_3 plus the magnetic action of the lamp current passing through the part of the winding M_3 from the left-hand end to the point D. It is obvious that the total magnetic action of these two currents will be less than the magnetic action of a current equal to the sum of the two and passing through the entire winding. Hence, since the magnetic action on the armature A_2 is to be the same when the tension of

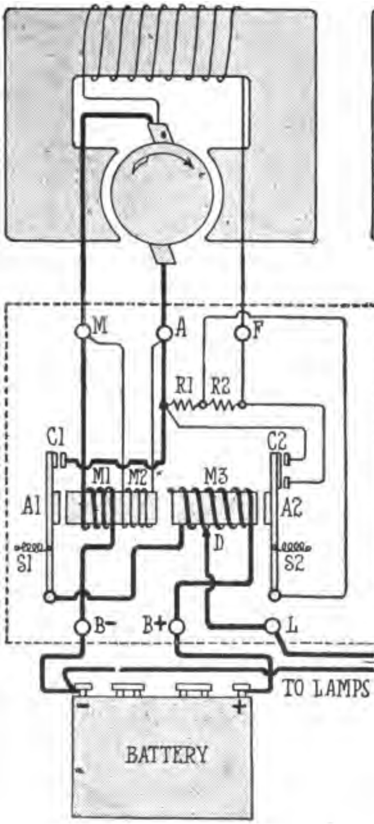


Fig. 149—*Here the lamp load affects the vibrator so that the generator output increases when the lamps are lighted and the engine is charging the battery*

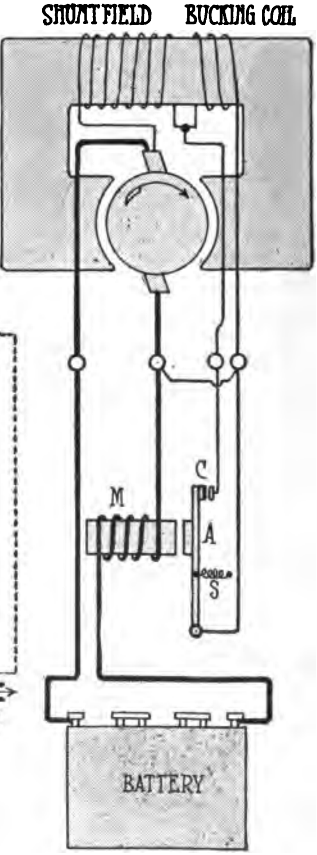


Fig. 150—*This system of electrical connection makes use of a vibrating magnet in combination with a bucking coil. Such regulation is seldom encountered, however*

the spring S_2 is overcome, no matter whether the lamps be turned on or not, the sum of the lamp current and the current to the battery will be greater than the current to the battery when the lamps are turned off.

Energizing the Bucking Coil Intermittently by Means of a Magnetic Vibrator: A system of regulation, that is very seldom encountered, makes use of a vibrating magnet, similar to those previously described, in combination with a bucking coil. The principle of operation of such a system can be easily understood by reference to Fig. 150. The resistance R in Fig. 145 has been replaced by an additional field winding, which carries a current when the contact C is open. The direction of the current in the bucking coil is such as to produce a magnetizing effect in the opposite direction to that produced by the current in the main or shunt field winding. Some systems have made use of the bucking coil in parallel with the resistance, and only a part of the shunt field current passes through the bucking coil.

Electromagnet Used in Combination with a Carbon Field Resistance: The carbon used in the construction of field resistances is in two forms. One form consists of a large number of small carbon discs piled on top of each other and normally held together tightly under the tension of a spring, so that their resistance is quite low. The armature of the regulator is attached to the spring so the magnetic pull on the armature lessens the tension of the spring holding the carbon discs together and the resistance of the combination is increased, due to the fact that the various discs are making poorer contact with each other than they were when the tension of the spring holding them together was at its maximum value. The magnetic pull on the armature of the electromagnet will depend on the value of the current in the winding, which may be arranged to vary as the current from the generator by connecting the winding in series with the generator, or as the voltage of the generator by connecting the winding to the terminals of the generator. In the first case the winding will consist of a small number of turns of large wire, while in the second case the winding will consist of a relatively large number of turns of small wire. Carbon resistances composed of discs have been used in some models of the U. S. L. and Aplco equipment.

The other form of carbon in the construction of field resistances is the finely divided, or powdered, carbon in combination with small flakes of mica. This mixture of carbon and mica is carried in a suitable cup, or cylinder, and is compressed by a plunger which normally is held against the mixture under the action of a spring. The action of the spring is counteracted to varying degrees by the magnetic pull of an electromagnet, and the pressure of the plunger against the mixture of carbon is varied. The small particles of mica give to the mixture a springiness which causes the particles of carbon to separate to a certain extent when the pressure is reduced and as a result increases the resistance of the mixture. A good example of this type of carbon resistance is found in the voltage regulator of the Bosch company.

The operation of the U. S. L. regulator that has the carbon-disc resistance may be understood readily by reference to Fig. 151, which gives a wiring diagram of the connections. In this system two storage batteries are used. They are charged in parallel and discharged in series through the starting motor, the change in connections being made by the starting switch. The connections in the starting switch for both the generating and starting positions are shown. The circuits through the regulator may be traced as follows: Starting with the generator terminal marked A+, which corresponds to the positive set of brushes, go to the contact G+ of the touring switch and then to the terminal A+ on the controller. From the terminal A+ on the controller you may return to the negative set of brushes on the generator by two circuits. One of these circuits is from A+ on the controller through the lower coil, called the shunt winding in this case, to the terminal B2–; thence to the terminal B2– on the starting switch; thence from A– on the starting switch to A– on the generator; thence through the series winding on the fields to the negative set of brushes, and then through the armature winding back to the starting point, or generator terminal A+. The second circuit between the terminal A+ on the controller and the negative set of brushes on the generator is through the carbon resistance indicated at the top of the regulator to the terminal F+; thence through the shunt field winding to the junction of the shunt and series field windings, which corresponds to the negative set of brushes on the generator; and then through the armature winding back to the starting point, or generator terminal A+.

As the voltage of the generator builds up, due to increase in speed and field strength, the current in the shunt winding on the controller, which is connected between the terminals A+ and

B2–, increases in value. When the magnetic pull due to the current in the shunt winding reaches a certain value, an armature of the electromagnet is drawn over and the contacts between the terminals A+ and B2+ on the controller are closed. The closing of these contacts completes a circuit between the positive and negative terminals of the generator through the batteries. This circuit may be traced as follows: From A+ on the generator through the contacts G+ on the touring switch to the ter-

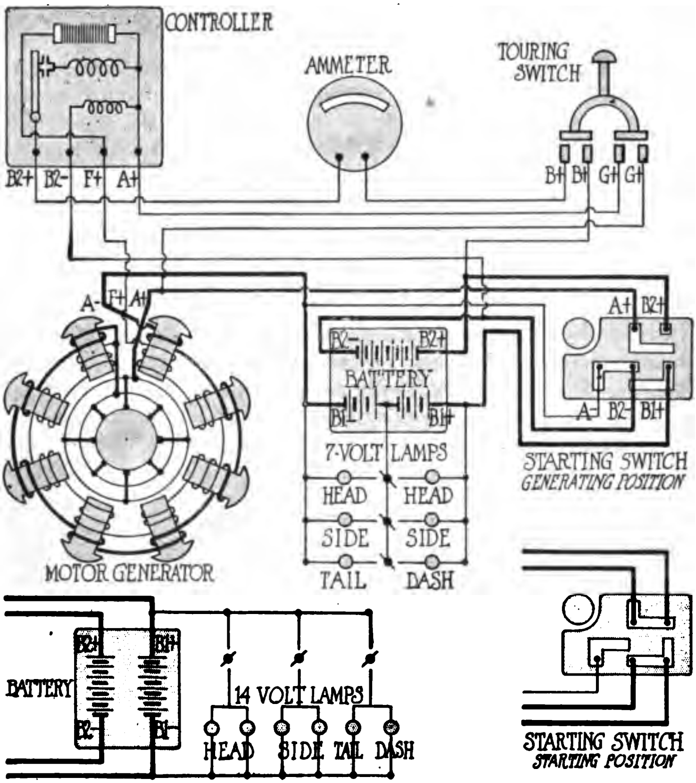


Fig. 151—This wiring diagram shows the connections of the U. S. L. regulator and cutout. The field resistance is in the carbon disc form

minal A+ on the controller; thence through the series winding and contacts to the terminal B2+ on the controller; thence through the ammeter to the contacts B+ on the touring switch.

From the right-hand contact, marked B+, on the touring switch, the circuit divides, one going directly to the terminal B2+ of the upper battery through the battery to the terminal B2–, and then to the negative terminal of the generator. The second circuit goes to B2+ on the starting switch; thence to B1+ on starting switch; thence to the terminal B1+ of the lower battery through the battery to the terminal B1–, and thence to the negative terminal of the generator. When the above connections are made the generator is charging the two batteries in parallel and the ammeter is indicating the sum of the currents in the two batteries, assuming no lights are turned on. The current in the series coil of the controller is the same as that indicated by the ammeter. When the current in this series coil exceeds a certain value the magnetic action of the current causes sufficient pull on an armature to partially overcome the action of the adjusting spring, and the force holding the carbon discs together is reduced, causing an increase in the resistance they offer. Hence, the value of the field current and the value of the voltage generated will decrease. A description of the operation of the remainder of this system will be given later. The complete controller with the cover removed is shown in Fig. 152, and the more important parts are marked. The indicator gives a visible indication as to whether the cutout is operating or not, the end of the pointer showing through a small hole in the top of the cover.

Electromagnet Used in Opening the Field Circuit of the Generator: The Aplco systems make use of an electromagnet whose winding is connected directly to the terminals of the battery. The armature of this electromagnet controls a set of contacts which normally are closed and connected in series with the field winding of the generator. When the voltage of the battery has reached a value ample to produce current in the winding of the electromagnet so that the magnetic pull on the armature overcomes the tension on the adjusting spring, the contacts open and the current in the field winding is reduced to zero value. This is neglecting the effect of residual magnetism. The battery will not be charged until its voltage drops to a certain value, depending on the adjustment of the spring controlling the armature on which the contacts are mounted. This will allow the contacts in the field circuit to close again.

Varying the Value of the Field Resistance by a Solenoid: The Adlake equipment has a regulator which consists of a resistance whose value is controlled by the magnetic action of a solenoid. The device, in brief, consists of an arm pivoted at one end and equipped with a carbon brush on the other end. This carbon brush moves over a number of metal segments arranged in the form of an arc of a circle and connected together by a small coil of resistance wire. The field circuit of the generator has one terminal connected to the arm and another connected to one end of the series of segments. The position of the carbon brush on the segments will determine the portion of the total resistance connected in series with the field winding. For example, when the carbon brush is on the segment to which the field winding is connected, no part of the resistance will be in series with the field; on the other hand, if the carbon brush is on the segment farthest removed from the one to which the field winding is connected, all the resistance will be in series with the field winding. The normal position of the arm corresponds to the one in which there is no part of the resistance in series with the field winding. The position of the rheostat arm is determined by the combined magnetic action of the current in the winding of the solenoid about the iron core marked T, Fig. 153, and the weight of the plunger R, the core and plunger being attached to the

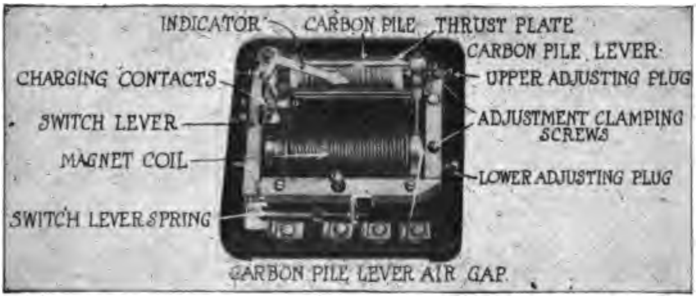


Fig. 152—The cover of the U. S. L. regulator and cutout has been removed, and the more important parts are marked. The indicator acts as a barometer for the cutout

opposite ends of a short cable which passes over a grooved wheel attached to the rheostat arm. The weight of the plunger R may be increased by adding more shot and decreased by removing some of the shot. Increasing the weight of the plunger R will increase the current required to produce a given movement of the rheostat arm.

The entire output of the generator passes through the winding of the solenoid, and as this current output tends to exceed the value for which the adjustment has been made the iron core marked T will be drawn into the solenoid, causing the carbon brush on the end of the rheostat arm to move down over the segments. The value of the resistance in the field circuit will be increased, causing a decrease in the value of the field current and, hence, a decrease in the electrical pressure in the armature of the generator.

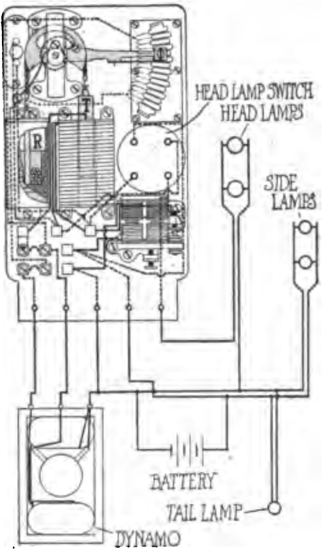


Fig. 153—*A solenoid controls the value of the field resistance in this Adlake-Newbold regulator and cutout*

A wiring diagram of the Adlake-Newbold combined regulator and cutout is shown in Fig. 153. The complete device, with cover removed, is shown in Fig. 154. The generator is of the shunt-wound type and the field circuit may be traced as follows: Starting with the generator terminal marked +D, go to the corresponding terminal on the controller marked +D; thence to the fuse clip marked 6; thence to the terminal of the rheostat marked 3; thence through the resistance coils to the carbon brush on the end of the rheostat arm; thence to the screw 19; thence through the flexible connection to the screw 18; thence to the fuse clip marked 2; thence through the fuse 5 to the clip 1; thence to the terminal +F on the regulator; thence to the corresponding terminal on the generator marked +F; thence through the shunt field winding to the terminal of the generator –D; thence through the armature winding to the starting point +D.

A second circuit exists between the terminals +D and –D of the generator, even though the contacts of the cutout be open. It may be traced as follows: Starting with the terminal +D; thence to the fuse clip 6; thence through the fuse 10 to clip 7; thence through a winding on the solenoid to the connecting terminal 20; thence to the point X on the stationary contact of the cutout; thence through the windings of the two upper electromagnets in series to the connecting terminal 15, and then to the terminal –D on the generator.

As the voltage of the generator builds up, the current in the circuit just traced through increases, and when the magnetic pull produced by the current in the two upper electromagnets is sufficient to draw up the two lower electromagnets, which are mounted on the piece of iron Z, the cutout contacts at W1 and W2 will be closed. The closing of the cutout contacts will complete a new circuit which may be traced as follows: Starting with the generator terminal +D; thence through fuse 10; thence through a winding on the solenoid to the connecting terminal 20; thence to the point X and to the upper, or stationary, cutout contact W1; thence to the lower cutout contact W2; thence through the windings of the two lower electromagnets in series to the connecting terminal 14; thence to the controller terminal +B; thence to the positive terminal of the battery marked +B through the battery to the terminal –B; thence to the negative terminal of the generator, and thence through the armature winding to the terminal +D, or starting point.

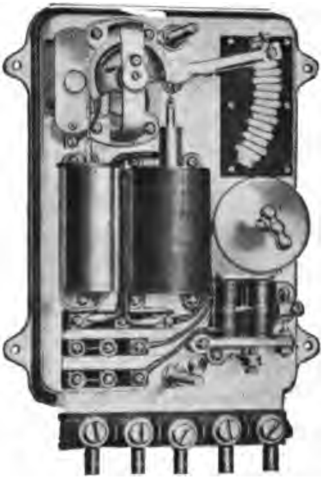


Fig. 154—This shows the Adlake-Newbold device with the cover removed. The generator is a shunt wound type

In tracing this last circuit, the lamps were assumed to be turned off. The current in the two lower electromagnets assists in holding the cutout contacts closed as long as the battery is charging, but should the battery start to discharge the magnetic action will be opposite that produced by the upper electromagnets and the cutout contacts will open. The front lamps take their current through a special switch, whose connections are such that the resultant magnetic action of the generator current in the solenoid is less with the front lamps on than without them. Hence the current output of the generator is increased when these lamps are turned on. The switch in the upper left-hand corner, marked N in Fig. 153, is for getting the night rate of current output from the generator continuously should conditions demand it.

Solenoid and "Mercury Well" Control of Field Resistance: A number of the earlier Delco systems were equipped with a regulator known as the mercury well type. A cross-section of one is shown in Fig. 155. This regulator consists of a winding, A, which surrounds the upper end of a mercury tube, B. Inside this mercury tube is a plunger tube, C, with a winding of resistance wire, R, about its lower end. One end of the winding R is attached to the cover end of the plunger tube and the other end is connected to a needle, D, carried in the center of the lower end of the tube. The lower portion of the mercury tube is divided by an insulating tube into two concentric compartments, the plunger tube being partly immersed in the outer compartment and the lower end of the needle N in the inner compartment. The space in the mercury tube above the mercury is filled with a special kind of oil, which serves the double purpose of protecting the mercury from oxidization and of lubricating the plunger tube. The whole device is supported by a bracket, B.

The terminals of the winding A are connected to the two wires leading from the generator brushes, and as the voltage of the generator increases the current in the winding increases. Hence, there is an increase in the magnetic pull on the iron plunger tube C. As the lower end of the plunger tube is withdrawn from the mercury, due to the magnetic pull of the winding A, more resistance is inserted in series with the shunt field winding of the generator, as the field current must now pass through a greater length of the wire in the winding R in passing from the needle N to the mercury in the outside mercury well. With this increase in resistance in the field winding there is a smaller field current for a given terminal voltage. Hence, the terminal voltage of the generator does not increase as rapidly as it would if no resistance were inserted in series with the field winding. As the charging of the battery continues the voltage of the system increases, and the magnetic pull produced by the winding A increases, causing more resistance to be inserted in the field circuit and thus preventing an excessive charging current while the battery is approaching a condition of complete discharge. With a decrease in speed of the generator, there will be a decrease in the generated voltage, thus causing a decrease in the magnetic pull produced by the current in the winding A and, hence, a decrease in the resistance of the field circuit, which prevents the voltage decreasing as rapidly as it would otherwise.

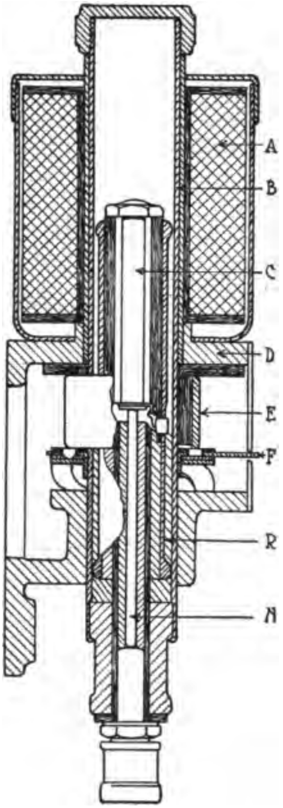


Fig. 155—*A cross-section of the mercury well regulator. Some of the earlier Delco systems used this type*

A variable resistance, E, is connected in the supporting bracket D and connected in series with the winding H. The value of the portion of this resistance in series with A may be adjusted at any time by a lever, F. The object of this adjustment is to take care of the variations in the battery voltage, due to changes in temperature.

An Electromagnet Used in Controlling the Connections of the Field Circuits: In some of the older types of Delco equipment an electromagnet was used to change the connections of the field windings and to regulate the output of the generator as follows: The field of the generator is produced by permanent magnets which are provided with several shunt field windings. The connections of these shunt field windings are controlled by the electromagnet, whose magnet action is governed by the output of the generator. At low engine speeds the shunt fields are connected so that they assist the permanent magnets in producing a magnetic field for the armature to revolve in. With an increase in voltage of the generator, due to an increase in speed, the field windings are disconnected, the permanent magnets act alone to produce the magnetic field and the increase in voltage is not as great as it would be had the shunt field windings remained connected. With a still further increase in voltage the shunt field windings are again connected with a resistance in series, but in such a manner that the current in them produces a magnetic effect opposite to that produced by the permanent magnets and the field strength is reduced, which counteracts to a certain extent the increase in speed. The resistance in series with the field winding is removed by a change in connections when the voltage reaches a value produced by the highest engine speeds and the maximum magnetizing action of the shunt fields oppose the permanent magnets.

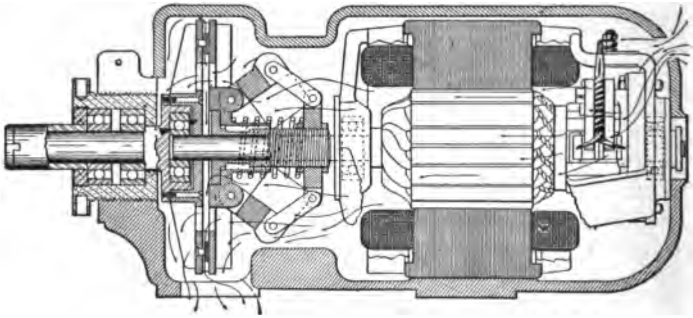


Fig. 156—*A slipping clutch operates this Gray & Davis generator*

Mechanical Regulation

Generator Operated at a Constant Speed by a Slipping Clutch Controlled by a Centrifugal Governor: If a shunt generator be operated at a constant speed, the voltage will build up to a definite value and remain practically constant. The value of this definite voltage can be adjusted by charging the value of the resistance of the shunt field winding and, unless there is a change in the speed or resistance of the field, will remain practically constant so long as there is no change in the value of the current the generator is delivering. The regulation of a number of different systems put on the market by the Gray & Davis Co. is accomplished in this manner. In the systems a series field winding usually is provided. This series field is arranged to carry all or a certain part of the current delivered by the generator, and its magnetizing action assists the magnetizing action of the shunt field and causes an increase in the value of the field strength with an increase in current delivered and, hence, an increase in generated voltage with an increase in the current output. The magnetizing action of this series field is usually adjusted so that the increase in generated voltage is just enough to counteract any loss in the armature and connecting leads, due to the increased output which results in the voltage at the terminals remaining fairly constant for all loads. The cross-section of a generator of this type made by the Gray & Davis Co. is shown in Fig. 156, and the operation of the driving clutch will be apparent after a careful inspection of the figure.

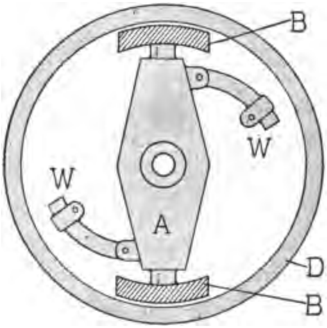


Fig. 157—*This Auto-Lite friction clutch also tends to maintain a constant speed*

A friction clutch used by the Auto-Lite Co. in some of their earlier equipments for operating the generator at a constant speed is shown in Fig. 157. The governor consists of a drum, D, fastened to the driving shaft and of two friction shoes, B, each being attached to a weight, W, and normally held against the inside surface of the drum by the action of coiled springs placed in the ends of the arm A. As the speed at which the arm A rotates increases there is a tendency for the weights W to be thrown outward from the point about which they rotate. The two arms carrying the weights are pivoted at the ends of the arm A, and as the weights are thrown outward the action of the springs holding the friction shoes against the cylinder is decreased. The speed at which the clutch slips may be changed by moving the weights W toward or away from the points at which the arms carrying them are pivoted. The nearer the weights are to these points the higher the speed necessary for the clutch to slip and likewise, the farther these weights are away from these points the lower the speed necessary for the clutch to slip.

Centrifugal Governor Used in Inserting Resistance in the Charging Circuit: A good example of this type of regulation is found in a machine manufactured by the Vesta Co. In this machine the position of a rheostat arm on the contact segments of a small rheostat is controlled by the action of a centrifugal governor. The end contact of the rheostat, on which the end of the rheostat arms rests normally and at low engine speeds, is not electrically connected to any of the other circuits. The charging circuit for the battery is connected to the rheostat arm, and when the end of the arm is on this insulated segment the electrical connection between the generator and the battery is not complete. The end of the arm travels over the contact segments of the rheostat with an increase in speed, and when it comes in contact with the second point the circuit connecting the generator and battery is closed. A further movement of the arm inserts resistance in series with the generator and battery and thus prevents an excessive charging current.

Regulation by Ampere-Hour Meter

Some of the earlier Delco systems made use of an ampere-hour meter that measured the quantity of electricity put into and taken out of the battery and gave an indication of these quantities on a suitable dial. The pointer on the indicating dial of this instrument travels in one direction when the battery is charging and in the opposite direction when the battery is discharging. The difference in the indications of this pointer at two different times is a measure of the net quantity of electricity put in or drawn from the battery during the interval between taking the two readings. A double set of contacts is carried in the containing case of the instrument, through which the field current of the generator must pass. A movement of the pointer of the meter past a certain position causes one set of these contacts to open and, with further movement past this point in the same direction, causes the second set of contacts to separate

When the first set of contacts is opened a resistance is inserted in series with the field and the charging current is reduced. When the second set of contacts opens the field circuit is opened altogether, and the charging of the battery is practically stopped, as there is no field, except that due to residual magnetism, for the armature of the generator to revolve in. The reverse operation of these contacts takes place when the battery discharges and the pointer is turned in the opposite direction. With this system the rate at which the battery is charged is governed by the amount of charge in the battery. The hand on the meter must be moved in the direction of charge at certain intervals, because there must always be a greater number of ampere-hours put into the battery than it can supply. The meter hand is mounted in such a way that this adjustment easily may be made.

Suggestions in Adjustment of Regulators

The adjustment of the regulator equipment on the different cars is made by the manufacturers of the equipment or at the factory where the equipment is installed and is correct for that particular make and model of car under ordinary conditions. Under no conditions should this adjustment be changed unless the person making the change is positive that such a change is required, and even then it is best to have an experienced man make the adjustment, as more damage may be done than good. Difficulties arising from improper change in the adjustment of the regulator may not be apparent at the time the change is made, and the car may run for a considerable period before there is definite evidence of the difficulty. In the majority of cases low generator output is due to improper care of the commutator and brushes, in not keeping all the various electrical connections clean and tight or in not giving the battery the necessary attention.

Occasionally unusual conditions may arise in the operation of the car, which will demand an increase in the generator output. For example, the addition of extra electrical equipment may necessitate an increase in the rate at which the battery is charged for a given speed of the car. It is always advisable to make sure that you are not demanding a larger output from the battery than it is capable of handling under ordinary conditions, as permanent damage to the electrical equipment will be the ultimate result. In some cases a car may be driven a great deal more at night than in the daytime, and with the lamps lighted the demands on the battery will be increased. Under these conditions it is necessary to increase the rate at which the generator will charge the battery for a given engine speed. Owing to the lower efficiency of the battery in the winter and the greater use of the lamps, the charging rate of the generator should, as a rule, be increased. It may be advisable to lower the charging rate of the generator or to stop the charging operation altogether on a long drive, by disconnecting the generator, short-circuiting it or removing the field fuse, depending on the kind of generator and the method of regulating its output. In some cases a special switch, called the touring switch, is provided. This produces the necessary changes in connection when it is turned to the position that causes a reduction in generator output.

CHAPTER XVI

Electric Motors

Principle of the Direct-Current Motor

IF a wire in which there is a direct current be placed in a magnetic field in such a position that the center of the wire does not correspond in position to the direction of the magnetic field, a force will act on the wire, due to the action of the current in the wire and the magnetic field on each other. This force is present in the generator when the machine is operating and there is a current in the armature, and it tends to cause the armature to revolve in the opposite direction to that in which the gasoline engine is rotating the armature. If the strength of the magnetic field or the value of the current in the wire increases, the position of the two with respect to each other remaining constant, the force tending to move them with respect to each other will increase. The value of the force between the magnetic field and the wire depends on their relative positions; it is at its maximum when the center of the wire and the direction of the magnetic field are at right angles to each other, and at its minimum when the center of the wire and the direction of the magnetic field are parallel to each other.

The production of the force acting on the conductor may be explained as follows: A conductor, W, carrying a current away from the observer and placed in a magnetic field, H, whose direction is from the left toward the right is shown in Fig. 158. The current in the conductor tends to produce a magnetic field about the conductor in a clockwise direction, which results in the main magnetic field being strengthened on the upper side of the conductor, where the two fields are in the same direction, and weakened on the lower side of the conductor, where the two fields are in opposite directions. As previously explained two magnetic fields cannot exist in the same space at the same time but combine to form a resultant magnetic field. Since the magnetic field is so much stronger on the upper side of the conductor than on the lower side, the conductor is acted on by a force, F, which tends to move it down or toward the bottom of the field

The Left-Hand, or Motor, Rule

A definite relation exists between the direction of the current in a wire placed in a magnetic field, the direction of the magnetic field and the direction of the force tending to move the wire with respect to the magnetic field. If the thumb and first and second fingers of the left hand be placed at right angles to each other, Fig. 159, the second finger pointing in the direction of the current in the conductor and the first finger in the direction of the magnetic field, then the thumb will point in the direction in which the conductor will tend to move. This simple rule is known as the left-hand, or motor, rule. If the direction of current in the wire be reversed, the direction of the magnetic field remaining constant, the direction of the force acting on the conductor will

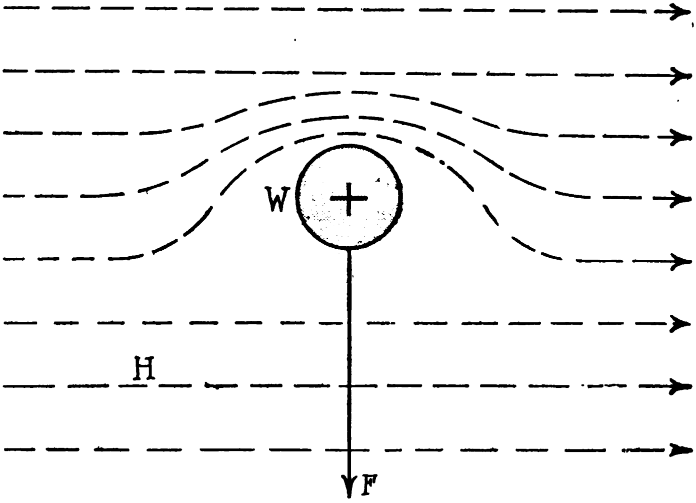


Fig. 158—The force acting on a conductor in which there is a current tends to move it up and down when the conductor is placed in a magnetic field

be reversed; or, if the direction of the magnetic field be reversed, the direction of current in the wire remaining the same, the direction of the force on the wire will be reversed. If, however, the direction of the current in the wire and the direction of the magnetic field are both reversed, the direction of the force on the wire will remain the same.

Generator and Motor Interchangeable

The essential parts of a direct-current motor are identical with those of a generator, namely, an armature and a magnetic field. The connection of the wires on the surface of the armature to the external circuit is made by a commutator, which serves to reverse the current in the various parts of the armature winding at the proper time, so that the force acting on the various wires tends to produce rotation in the same direction, and, as a result, continuous rotation of the armature is produced. Any direct-current generator may be used as a direct-current

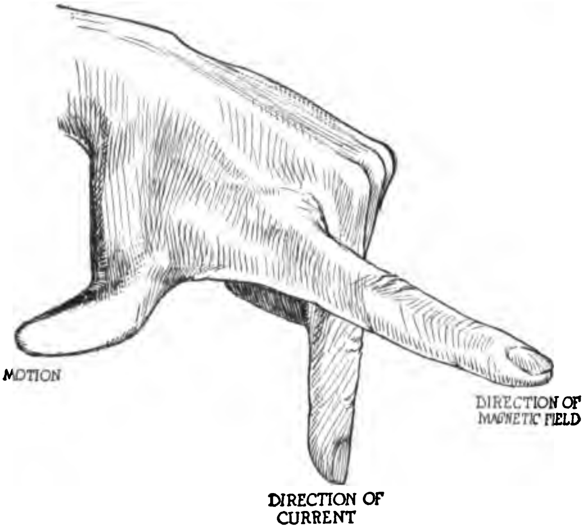


Fig. 159—The left-hand, or motor, rule is used to determine the direction of the conductor's movement when the directions of the conductor's current and the magnetic field are known

motor, or vice versa, their construction being practically the same.

Simple Experiment Illustrating Fundamental Principle of the Direct-Current Motor and Right-Hand Rule: A simple experiment may be arranged to verify the facts stated in the two previous sections, Fig. 160, which consists of a U-shaped piece of copper wire supported by two metal supports forked at their upper end so that the wire is free to turn and at the same time makes good electrical contact with the supports. The lower ends of the supports are connected to two binding posts as in the figure. A strong permanent magnet, M, is placed with its

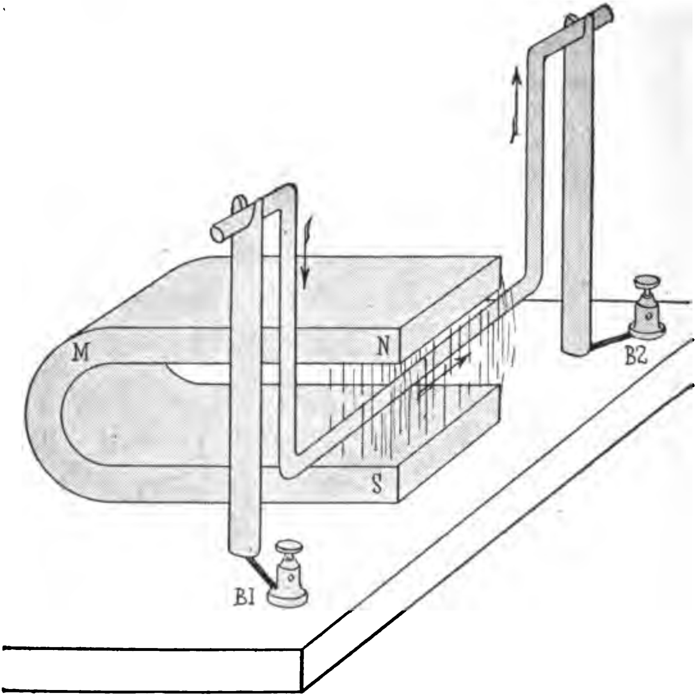


Fig. 160—*This simple experiment illustrates the fundamental principles of the direct-current motor and the right-hand rule* poles on opposite sides of the wire as indicated in the figure. If a current be sent through the wire, the wire will deflect from its normal position. The degree of this deflection will depend on the value of the current, and the direction of the deflection will depend on the direction of the current in relation to the direction of the magnetic field. When the north pole of the magnet is on the upper side and the current in the wire is in the direction indicated in the figure, the deflection or movement of the wire will be toward the left. If the magnet be turned over, that is, if the field be reversed, the direction of the deflection will be reversed, or if the current be reversed, the direction of the deflection will be reversed. The direction of the deflection will remain unchanged when the direction of the field and the direction of the current are reversed at the same time.

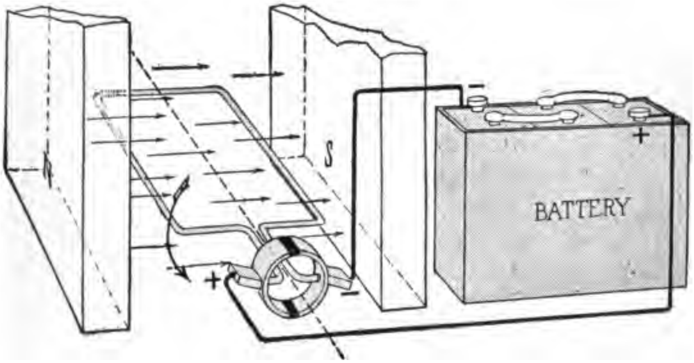


Fig. 161—In the operation of this two-part commutator the direction of the force acting on any part of the coil can be determined by application of the left-hand rule

Operation of Two-Part Commutator

If a single loop of wire be mounted on an axis which is at right angles to the direction of a magnetic field, Fig. 161, and a current be supplied to the coil by means of a two-part commutator and two brushes which rest on the commutator exactly opposite each other, a force will act on the sides and ends of the coil. The direction of the force acting on any part of the coil may be determined for all the different positions the coil may occupy when it turns on the axis supporting it by a simple application of the left-hand, or motor, rule. Remember that the force acting on the conductor is always perpendicular to the direction of the magnetic field; then proceed to investigate the force acting on the coil for various positions. The resultant force which tends to produce rotation acting on the two ends of the coil will be zero for all positions of the coil. The forces acting on the two sides of the coil will be equal in value for all positions, but the directions of the forces on the two sides will be exactly opposite each other. If the force on one side tends to move that side of the coil up, then the force on the other side tends to move that side down. The force acting on one side will always be up and the force on the other side will always be down, and both will remain constant in value as long as there is no change in the strength of the magnetic field or in the value of the current.

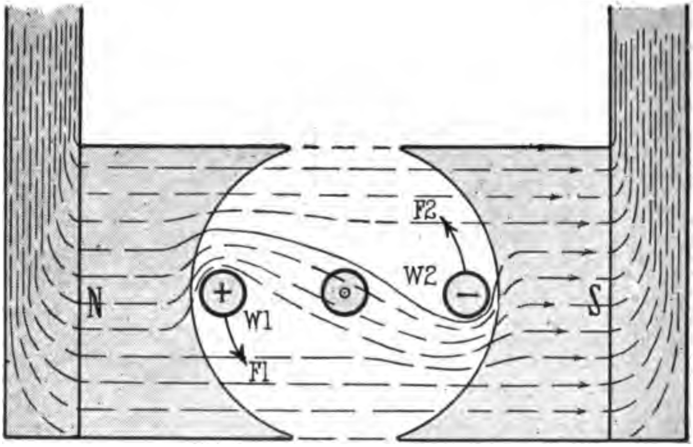


Fig. 162—When the coil is in a horizontal position, as shown by this cross-section, the effect of the forces tending to produce rotation is at a maximum

These forces on opposite sides of the coil, being in opposite directions, tend to rotate the coil, but the tendency for rotation is not constant in value for all positions of the coil. When the coil is in a horizontal position, as shown by the cross-section in Fig. 162, the effect of the forces in tending to produce rotation is at a maximum, because the two sides are then moving, as the coil rotates, perpendicular to the direction of the magnetic field. But for any other position of the coil with respect to the direction of the magnetic field, such as the one in Fig. 163, the effect of the forces tending to produce rotation will be less, and this effect will continue to decrease as the coil moves from a position parallel to the field toward a position perpendicular to the field, as in Fig. 164, where the force producing rotation will be zero. The relation of the forces tending to rotate the coil for different positions of one complete revolution may be represented by a curve, Fig. 165, in which points along the horizontal lines correspond to different positions of the coil as measured in degrees from a position perpendicular to the direction of the magnetic field. The relation of the lengths of the vertical lines correspond to the relation between the values of the forces tending to produce rotation for the different positions.

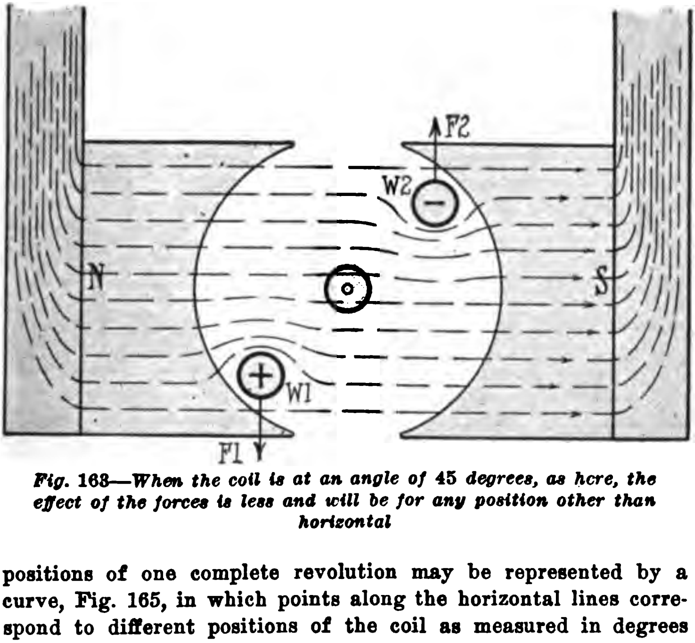


Fig. 163—When the coil is at an angle of 45 degrees, as here, the effect of the forces is less and will be for any position other than horizontal

When the coil becomes perpendicular to the magnetic field the two commutator segments exchange positions with respect to the brushes, and as a result the current in the coil reverses in direction. With a reversal in the direction of current in the coil, there is a reversal in the direction of the forces acting on the two sides, so that they tend to move across the magnetic field in directions opposite to those before the current in the coil was reversed.

It is obvious from the preceding paragraphs that the force acting on the coil tends to produce a continuous rotation, provided the magnetic field does not change in direction and that the brushes are properly placed on the commutator. The value of this force, however, fluctuates in value. When the coil is perpendicular to the direction of the magnetic field it is zero, and if the coil should happen to stop in this position, there would be no tendency for rotation no matter how much current in the coil or how strong the magnetic field. Such an arrangement would not be at all satisfactory, on account of the fluctuation in the turning force on the coil and also because this force is zero for two positions of the coil in each revolution. The turning force may be made nearer constant in value and at no time zero by more coils and more commutator segments.

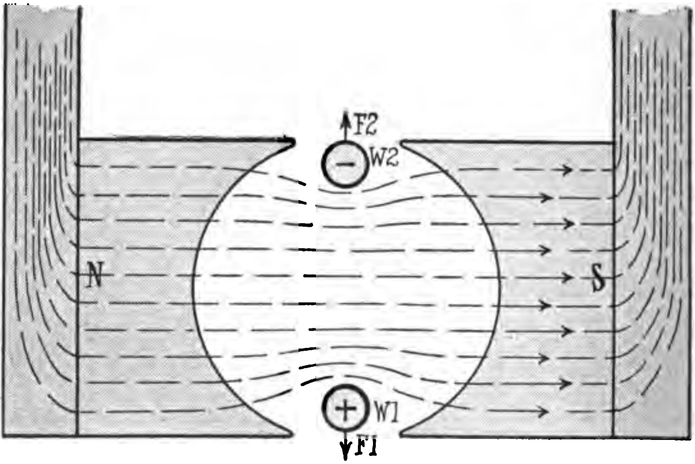


Fig. 164—When the plane of the coil is perpendicular to that of the magnetic field, as here, the force producing rotation is zero

Multiple-Coil Armatures

If two coils of wire, similar to the one described in the previous section, be mounted on an axis at right angles to each other, with the four terminals connected to a four-part commutator, the terminals of each coil being connected to opposite segments, Fig. 166, then the force tending to turn the two coils will pulsate in value as follows: Since the two coils are at right angles to each other, the forces acting on them will likewise be at right angles to each other. If the currents in the two coils are equal in value when they are connected, assuming they remain so for one complete revolution, then the forces acting on the two coils may be represented by two curves, as in Fig. 167. Both coils do not carry current at the same time, since they are connected to independent commutator segments and the brushes rest on segments exactly opposite each other. Each coil is connected in circuit for each revolution only one-half of the time, but this time is split into two parts and each independent connection lasts only for one-fourth of a revolution. By properly placing the brushes it is possible to get a continuous turning force acting on the combination of coils, and the best position for the brushes is such that one coil is disconnected and the other one connected to the external circuit when they are making the same angle with the direction of the magnetic field, namely, 45 degrees. This position of the brushes corresponds to the point where the curves cross each other, Fig. 167, and the

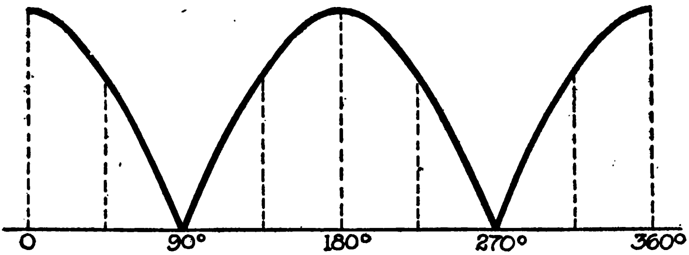


Fig. 165—*This curve shows the variation in the force tending to rotate a coil connected to a two-part commutator when it is placed in a uniform magnetic field. The angles are measured at a position when the plane of the coil is parallel to the magnetic field* resultant force acting on the two coils may be represented by the upper parts of the curves, or the shaded portion.

By increasing the number of coils and commutator segments the force acting on the coils will become nearer constant in value. This type of armature is not satisfactory for direct-current motors, as only those coils whose commutator segments are under the brushes at any particular time are in use. An armature winding of this type is called an open-circuit winding.

A better form of winding for direct-current motors, called a closed-circuit winding, makes use of all the coils all the time, except when the two commutator segments to which a coil is connected are in contact with a brush or brushes of the same polarity. One of the simplest forms of closed-circuit windings is shown in Fig. 168, which consists of a ring with four coils wound about it and interconnected by means of four commutator segments as in the figure. For convenience in referring to these coils they are designated by the letters A, B, C and D. The two coils A and C are short-circuited by the two brushes when they are in the positions shown in the figure. An instant later, however, coil A is in series with coil D on the left-hand side, and coil C is in series with coil B on the right-hand side,

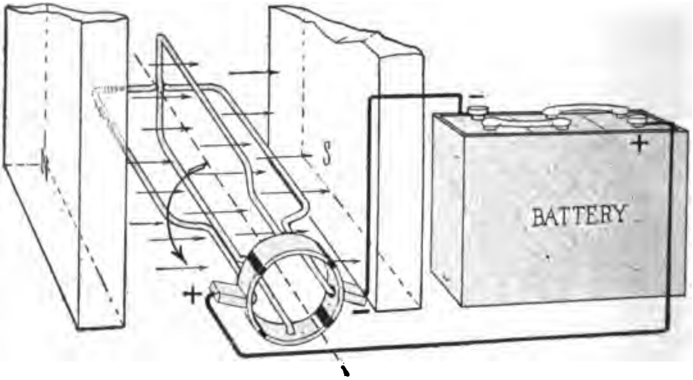


Fig. 166—When the terminals of two coils are connected to opposite segments of a four-part commutator, both coils do not carry current at the same time

and this connection remains until coils B and D are short-circuited by the brushes. An instant later coil D is in series with coil C on the right-hand side, and coil B is in series with coil A on the left-hand side. It is apparent that the coils opposite each other are short-circuited by the brushes at the same time when they are symmetrically arranged, as in this case, and as one coil leaves the right-hand circuit and enters the left-hand circuit at the lower brush, a coil leaves the left-hand circuit and enters the right-hand circuit at the upper brush. With this arrangement of coils and commutator segments, all the coils are in circuit with the external circuit all the time, except when they are short-circuited by the brushes. If the position of the brushes is such that the coils are moving parallel to the magnetic field when they are short-circuited, the total force acting on the combination tending to produce rotation will not decrease. The direction of the current in each coil when it has moved from the short-circuited position is opposite to what it was just before it reached this position. Hence, the movement of the coil with respect to the magnetic field is reversed, that is, if it tended to move up or down before being short-circuited, it tends to move down or up after the short-circuiting.

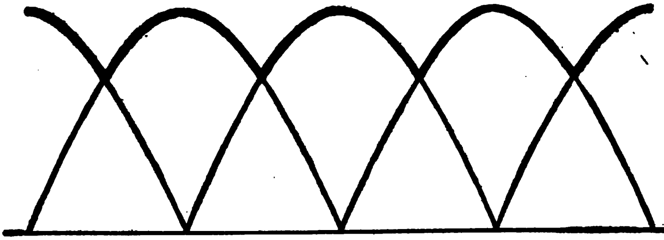


Fig. 167—The forces acting on the two coils connected as in Fig. 166 may be represented by these curves. The magnetic field is assumed to be uniform

The total force tending to produce rotation at any instant is equal to the sum of the forces produced by each of the coils. When the coils are symmetrically placed with respect to each other, the force exerted by any two which are exactly opposite each other might be thought of as being due to a single coil having a number of turns equal to the sum of the turns in the two coils. The four coils in Fig. 168 are symmetrically arranged and may be treated as two coils instead of four. The force exerted on these two coils may be represented by two curves, A and D, in Fig. 169, and the total force at any time will be equal to the sum of the forces on the two coils, since they are both in circuit all the time, except when they are short-circuited by the brushes. Then the force exerted by that particular coil is zero, because it is then moving parallel to the magnetic field. This total force may be represented by a third curve, whose height at any point is equal to the sum of the heights of the curves A and D. From this figure it is readily seen that the force tending to produce rotation is not constant in value, but fluctuates between a minimum value equal to the maximum force produced by a single coil and a maximum value equal to the combined values of the forces produced by the coils when they are each midway between their positions of minimum and maximum force. The number of pulsations in the force per revolution may be increased by increasing the number of coils and commutator segments, and an increase in the number of pulsations per revolution will result in a decrease in the difference between the maximum and the minimum values of the resultant force tending to produce rotation. Thus, with an increase in the number of coils and commutator segments, the resultant force becomes nearer constant in value, and the machine is capable of developing a fairly constant turning effort.

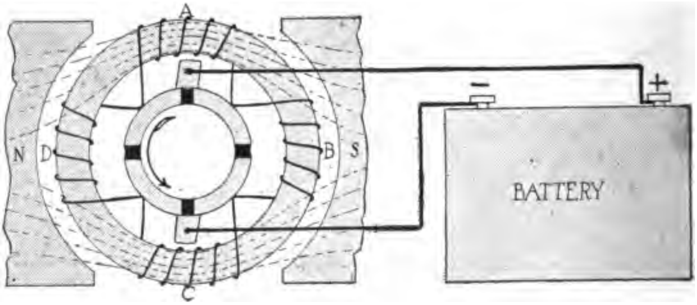


Fig. 168—The four coils in this form of closed-circuit winding are arranged symmetrically and, hence, may be treated as two coils

The type of armature used in this arrangement—called a ring type—is not used very extensively at present, but, on account of the simplicity in its construction and the connections of the coils, its operation is much more readily understood than that of the drum type, though the fundamental principle of both is exactly the same. After you have thoroughly mastered the operation of the ring type, the operation of the drum type, whether it be lap or wave sound, may be easily followed.

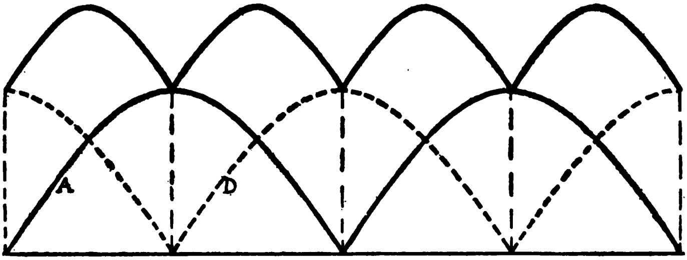


Fig. 169—This curve shows the variation in the force tending to turn a four-coil ring armature that has a four-segment commutator and is placed in a uniform magnetic field

Types of Magnetic Fields

In the majority of cases the magnetic field of a motor is produced by electromagnets, though a magnetic field may be produced by powerful permanent horseshoe magnets. Small machines are usually bipolar, that is, they have one north pole and one south pole which create the magnetic field in which the armature rotates. These magnetic fields assume a number of different forms, three of which are shown in Figs. 170a, 170b and 170c.

In larger machines it is customary to use multipolar field magnets, in which any even number of magnetic poles are arranged alternately around the armature, as in Fig. 171, which depicts a six-pole machine.

The magnetic circuit of a motor whose magnetic field is created by electromagnets usually consists of five parts, Fig. 171, as follows: First, the field cores C are the parts about which the coils carrying the magnetizing current are wound. Second, the yoke Y connects the field cores together at the outer ends, as in the figure, and serves the double purpose of completing the magnetic circuit between the field cores and of providing the necessary mechanical supports for the cores. Some machines have no yoke in the magnetic circuit, Fig. 170a. Third, the pole pieces P are the parts of the magnetic circuit next to the armature. They usually are cut to conform to the armature. They may be formed by properly shaping the ends of the field cores, or they may be pieces of metal entirely different from the ends of the field cores, being fastened to the field cores by bolts. The surfaces of the pole pieces next to the armature are called the pole faces and the projecting edges, when so constructed, are called the pole tips. Fourth, the armature core A conducts the magnetic flux between air gaps and at the same time serves as a mechanical support for the armature winding. Fifth, the air gap G is the intervening space between the pole piece and the armature.

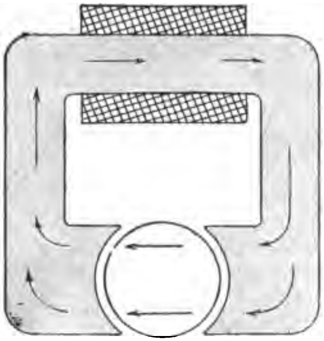


Fig. 170a—*Bipolar magnetic field with single field coil. The magnetic circuit has no yoke as most types have*

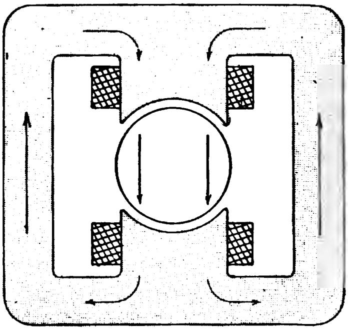


Fig. 170b—*Bipolar magnetic field with two field coils. Here a yoke supports the field cores and completes the circuit*

When the field windings are placed on the magnetic circuit as in Figs. 170b and 171, the magnetomotive force created by the current in one coil is in series with the magnetomotive force created by the current in some other coil, or the magnetomotive force on any magnetic circuit is that produced by the two coils in series. If the field windings be placed on the magnetic circuit as in Figs. 170a and 170c, the magnetomotive force acting on any magnetic circuit will be equal to that produced by a single coil. When the field windings are as in Figs. 170b and 171 only half as many ampere turns per coil as would be required if the coils were placed as in Figs. 170a and 170c will be required, assuming the total reluctance in the two cases to be the same. The magnetomotive force produced by the field coils in Fig. 171 acts upon two magnetic circuits and as a result is twice as effective as it would be if the coils were placed about the yoke between the poles.

Materials Used in the Construction of the Magnetic Circuit of a Motor: Four materials commonly are used in the construction of the magnetic circuit of a motor, that is, wrought iron, cast iron, cast steel and sheet steel. Several factors govern the selection of the materials to be used in a particular machine, such as initial cost, weight, efficiency demanded by purchaser, etc.

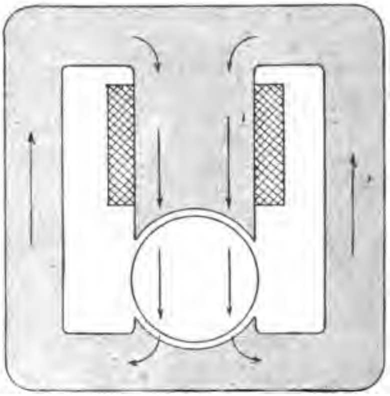


Fig. 170c—*Another type of bipolar magnetic field with single field coil*

The cheapest of these materials is cast iron, but its magnetic properties are poorer than those of any of the others, so the saving in the initial cost of the iron per pound might be more than overbalanced by the fact that a larger bulk of cast iron would be required to form a certain magnetic circuit than would be required if wrought iron, for example, were used. There also would be an increase in the cost of copper required to magnetize the magnetic circuit of large area, since the length of each turn would be more than if a better material were used or the area of the magnetic circuit were reduced.

Steel, on the other hand, is the best magnetic material and at the same time the most expensive. It is used where economy in weight and reduction in cross-section are desired. Machines used on electric motor cars, etc., are frequently made of cast or laminated steel on account of the large reduction in weight, which is a more important factor than the initial cost.

The magnetic circuits of motor cars are, as a rule, constructed of more than one material. Thus, the field cores may be of wrought iron, as that means a saving in copper since the length of the wire per turn would be less than if cast iron were used; the yoke may be of cast iron, as its area can be made larger than the field cores, and this increase in area will provide an ample magnetic circuit and also the mechanical strength necessary to support the field cores. The armature core usually is constructed of sheet metal to reduce the eddy-current loss to a minimum; the pole pieces may be a part of the field core and may be cast or laminated and bolted to the ends of the field cores. Numerous other combinations are used in the construction of the magnetic circuit of a motor, but these suggestions serve to illustrate some of the more important considerations involved in a proper selection of the materials for a particular case.

Magnetic Leakage

All the magnetic lines established by the field current of a motor do not pass through the armature core and, therefore, are not all useful in the operation of the motor. The ratio of the total number of magnetic lines that are produced to the number that are actually useful in the operation of the motor is called the coefficient of dispersion. The value of this coefficient is always greater than one, as there are always more lines of force produced than are actually useful. It is desirable to have the value of the dispersion coefficient as low as possible, and this is accomplished by constructing the magnetic circuit so it will have no abrupt bends, be as short as possible and have a low reluctance. The coefficient of dispersion can be reduced by placing the field winding on or near that part of the magnetic circuit having the greatest reluctance and by so shaping the magnetic circuit that the paths conducting the magnetic flux which is not useful will have a high reluctance as compared to the paths conducting the useful magnetic flux.

Excitation of Direct-Current Motors

Direct-current motors may be divided into three classes according to the method employed in exciting the field magnets. These are: (a) Shunt motors; (b) series motors; and (c) compound motors.

(a) The field winding of a shunt motor consists of a relatively large number of turns of small wire connected directly across the terminals of the machine or the circuit to which the machine is connected. A rheostat may be connected in series with the field winding, which may be used in adjusting the value of the current, or no rheostat may be used at all, the field current being allowed to vary with the voltage impressed across its terminals and the change in the resistance of the field winding, due to a change in its temperature. The connections of a shunt motor are shown diagrammatically in Fig. 172. The current in the field winding is independent of the current in the armature circuit as long as a change in armature current produces no change in the voltage impressed on the shunt field winding.

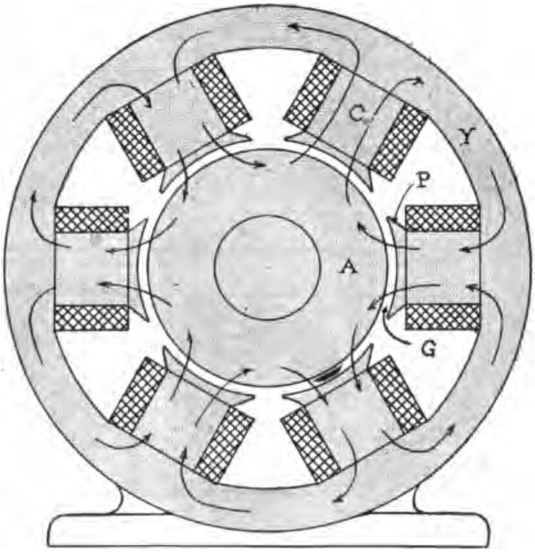


Fig. 171—*This six-pole magnetic field is marked to show the different parts of the magnetic circuit*

(b) In the series motor, the field winding consists of a relatively few turns of large wire connected directly in series with the armature, as shown diagrammatically in Fig. 173. The current in the field winding is the same as the current in the armature, and the strength of the magnetic field of the machine varies with the armature current. The field strength does not increase as rapidly as the current in the field winding, due to the fact that the reluctance of the magnetic circuit of the machine increases with an increase in the magnetic flux. In some cases a resistance is connected in parallel with the series field winding and only a part of the armature current passes through the field, the total current dividing inversely as the resistance of the two branches of the divided circuit.

(c) The field windings of a compound motor are a combination of the shunt and series windings, as shown diagrammatically in Figs. 174 and 175. The magnetic effects of these two windings may aid or oppose each other, depending on the manner in which they are connected. When the magnetizing actions of the series and shunt field windings act in the same direction about the magnetic circuit, the machine is called a cumulative compound motor; when the magnetizing actions of the series and shunt field windings are in opposite directions about the magnetic circuit, the machine is called a differential compound motor. In the case of the cumulative compound motor, the strength of the magnetic field increases with an increase in series field current, since the two magnetizing effects act together; in the case of the differential compound motor, the strength of the magnetic field decreases with an increase in series

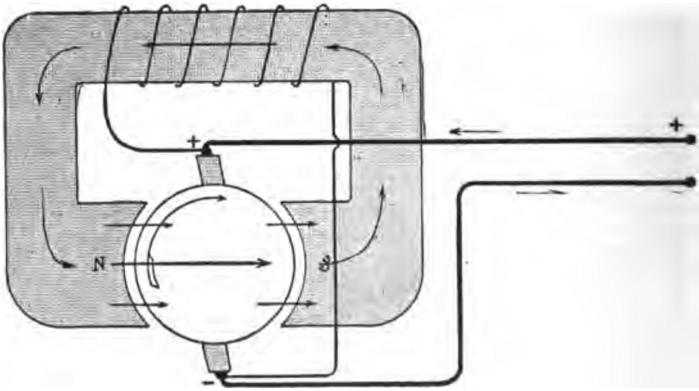


Fig. 172—A shunt field; the field winding is in parallel with the armature

field current, since the two magnetizing effects act in opposite directions.

Direction of Rotation of Machine When Changed from a Generator to a Motor: The direction in which a direct-current generator will operate when it is changed to a motor easily may be determined by the following simple relations. First, if both the direction of the armature current and the direction of the magnetic flux through the magnetic circuit of the machine remain unchanged, or if both are changed when the machine is changed from a generator to a motor, the direction of rotation will be reversed. Second, if either the direction of the armature current or the direction of the magnetic flux through the magnetic circuit be reversed, but not both, when the machine is changed from a generator to a motor, the direction of rotation will remain unchanged. Third, to reverse the direction of rotation of a motor it is necessary to reverse either the direction of the armature current or the magnetic flux, but not both.

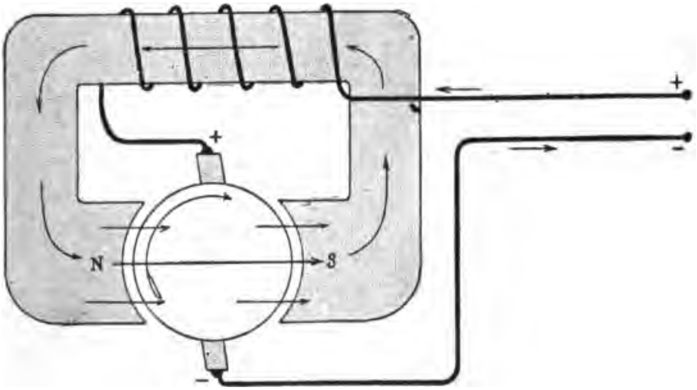


Fig. 173—*A series field winding; the field winding is in series with the armature and outside circuit*

If a shunt generator be changed to a motor, the polarity of the terminals remaining the same, the direction of rotation will remain unchanged, because the direction of the shunt field current remains the same and the armature current reverses in direction, it flowing from the negative to the positive terminal within the generator and from the positive to the negative terminal within the motor. If, however, the polarity of the machine be reversed when it is changed from a generator to a motor, the direction of rotation will remain unchanged, because the direction of the shunt current is reversed and the direction of the armature current remains constant. This leads to the general statement that a shunt generator when changed to a motor will operate in the same direction, regardless of the polarity of its terminals, provided there is no change in the connections of the armature and field windings with respect to each other.

If a series generator be changed to a motor, the polarity of the terminals remaining the same, both the armature current and the magnetic flux will reverse in direction, and the direction of rotation will reverse. If the polarity of the machine changes when it is changed from a generator to a motor, then the armature current and the direction of the magnetic field will remain unchanged, and the direction of rotation will be reversed. This leads to the general statement that a series generator when changed to a motor will operate in the opposite direction, regardless of the polarity of its terminals, provided there is no change in the connections of the armature and field windings with respect to each other.

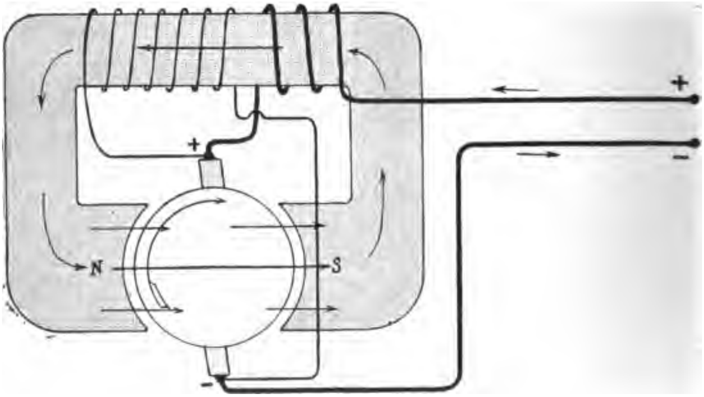


Fig. 174—A cumulative compound field in which the magnetizing action of the shunt and series field windings act in the same direction

If a cumulative compound generator be changed to a motor without any change in the connections of the field windings, the machine will become a differential compound motor. Likewise, if the machine is a differential compound generator, it will become a cumulative compound motor. The direction of rotation of such a machine when changed to a motor will depend on the relative effects of the series and the shunt field windings. For example, a differential compound motor may start up under the influence of the series winding, and after the shunt field current has had time to build up in value the armature may stop and start to rotate in the opposite direction.

Armature Reaction in a Motor

When a current is in the armature winding of a motor a magnetizing effect is produced, due to this current, and acts on the main

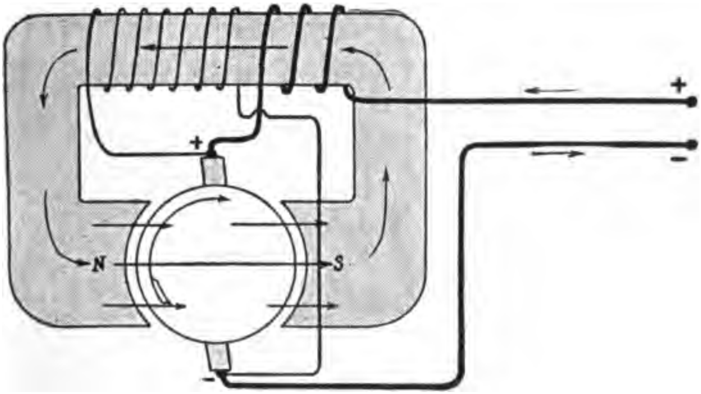


Fig. 175—A differential compound field in which the magnetizing actions of the shunt and series field windings are in opposite directions

magnetic field of the motor. This effect is called armature reaction. The effect of this magnetizing action, due to the armature current, may be illustrated as follows: Take a simple two-pole drum armature with a number of wires uniformly distributed over its surface and imagine it placed in a bipolar magnetic field, as in Fig. 176, which shows a cross-section through the armature and fields. Current is supplied to the armature winding by two brushes which rest on a commutator, and these brushes are placed in such a position that all the wires on the right of a vertical line through the center of the armature have a current in them from the surface of the paper and those on the left-hand side a current toward the surface of the paper.

If the magnetic poles have the polarity indicated in the figure, then the armature will tend to revolve in a counterclockwise direction, as indicated by the curved arrow. This direction of rotation easily may be determined by an application of the left-hand, or motor, rule. The plane, marked AC in the figure, which is perpendicular to the axis of the poles, and also the sheet of paper, is called the normal neutral plane. This normal neutral plane is perpendicular to the magnetic flux when there is no current in the armature winding. Now imagine the field current of the motor is zero and that a current is sent through the armature winding from some outside source. The current in the armature winding produces a magnetic field whose general direction through the armature core is downward, as in Fig. 177, when the current is in the direction indicated. Since the magnetizing effects of the armature current and the field current are present at the same time, they combine and form a resultant magnetizing effect which produces a magnetic field whose general direction is similar to that in Fig. 178. As a result of the magnetizing action of the armature current the magnetic field of a motor is twisted in a direction opposite to the direction of rotation of the armature, which is just the reverse of what occurs in the case of the generator. This twisting of the magnetic field results in the neu-

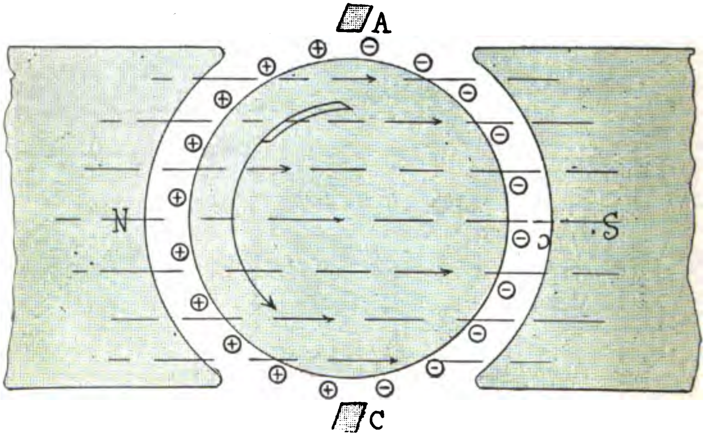


Fig. 176—Bipolar motor with magnetic field due to field current alone

tral plane, which is a plane perpendicular to the direction of the magnetic field, being moved back of the normal neutral plane, as shown by the line AC in Fig. 178.

Proper Position of the Brushes on a Direct-Current Motor

In order that the armature produce its maximum turning effort for a given armature current and magnetic field, it is necessary that the brushes be placed on the commutator in such a position that the current in the conductors on the surface of the armature reverses in direction when the wires are moving parallel to the magnetic field, or when they are in the neutral plane. It is necessary then that the brushes be moved backward, or opposite to the direction of rotation in the case of the motor, as the current in the armature winding increases, which increases the amount the neutral plane is twisted or moved from the position it occupies when there is no current in the armature winding. The brushes are usually moved

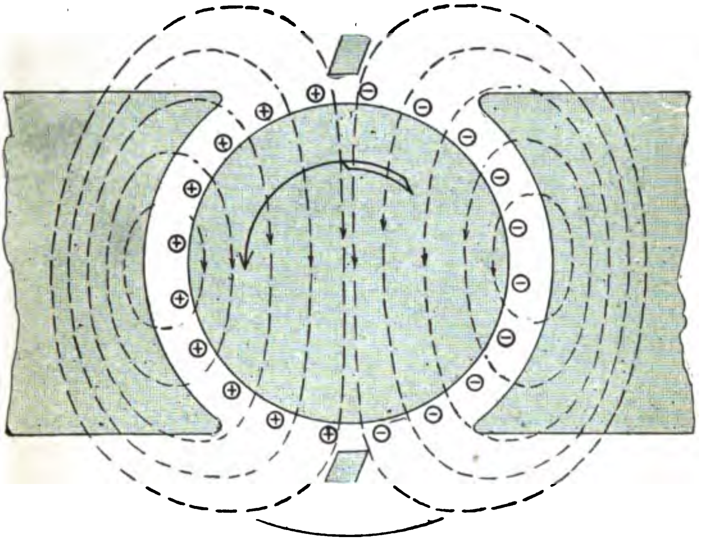


Fig. 177—*Bipolar motor with magnetic field due to armature current alone* a little farther back than the neutral plane, though there is a slight reduction in the turning effort to improve commutation, as explained in the section on Commutation. The position occupied by the brushes is called the commutating plane. The position the brushes actually occupy with respect to the poles of the machine will be quite different from that indicated in the figures dealing with armature reaction, so that the end connections of the wires to the commutator segments will be of the same length and form, but the direction of the current in the different wires will be the same as indicated in the figures. The brushes will occupy a position approximately midway between the positions indicated in the figures.

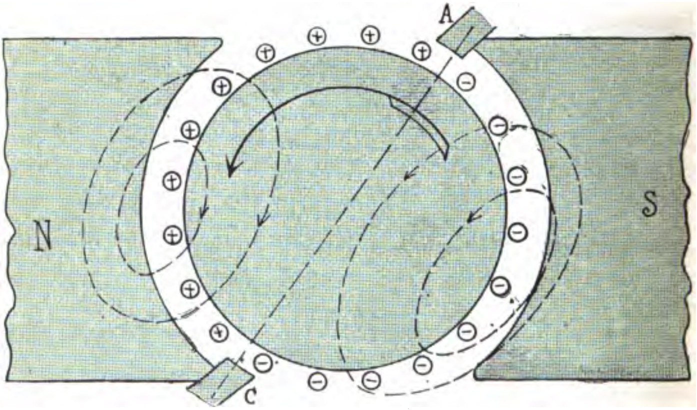


Fig. 178—Bipolar motor with magnetic field due to combined magnetizing effects of armature and field currents. Note position of brushes

With a change in the position of the brushes, the direction of the current in some of the wires on the surface of the armature will change. Thus, if the brushes are moved in a direction opposite to that in which the armature tends to rotate, as in Fig. 178, the direction of the current in the wires contained in the angle through which the brushes are moved will change, and the magnetic effect of a current in the armature no longer will be in a direction at right angles to the magnetizing effect of the field current but in a direction similar to that in Fig. 179. This magnetizing effect of the armature can be thought of as made up of two parts, one part acting perpendicular to the magnetizing effect of the field current, called the cross-magnetizing effect, and the other part acting parallel to the magnetizing effect of the field current, called the demagnetizing effect. The demagnetizing effect of the armature current tends to weaken the magnetic field of the motor, and the cross-magnetizing effect tends to distort, or twist, the magnetic field in a direction opposite to the direction in which the armature rotates.

The angle between the commutating plane and the normal neutral plane is called the angle of lag in the case of the motor, because the brushes are moved backward or given a lag with respect to the normal neutral plane, and it is called the angle of lead in the case of a generator, because the brushes are moved forward or given an angle of lead with respect to the normal neutral plane.

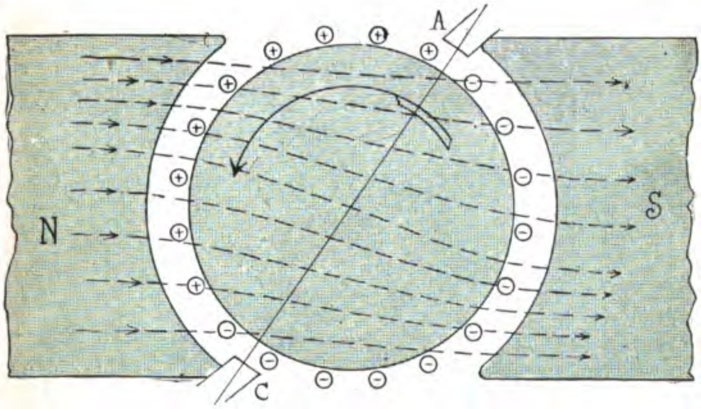


Fig. 179—*Bipolar motor with magnetic field due to armature current alone and with brushes moved back of normal neutral plane*

Demagnetizing and Cross-Magnetizing Ampere-Turns

The relative positions of the commutating planes for a generator and a motor are shown in Fig. 180, the full line representing the commutating plane of the motor and the dotted line representing the commutating plane of the generator. The direction of current in the armature wires corresponds to the motor connections, and the direction of rotation will be as indicated by the curved arrow. The wires between the two commutating planes on one side of the armature can be thought of as being in series with the wires between the two commutating planes on the opposite side of the armature and forming a number of complete turns about the armature core. The remaining wires may be thought of as forming a second set of turns. The product of the turns in the angle between the commutating planes and the current in each of these turns gives the value of what is called the demagnetizing ampere-turns, because their effect is to produce a weakening of the magnetic field of the machine. The product of the remaining turns and the current they carry gives the value of what is called the cross-magnetizing ampere-turns, because they act at right angles to the magnetizing effect of the field current of the machine. The turns in the angle between the commutating planes are called the demagnetizing, or back, turns and the remaining turns are called the cross turns.

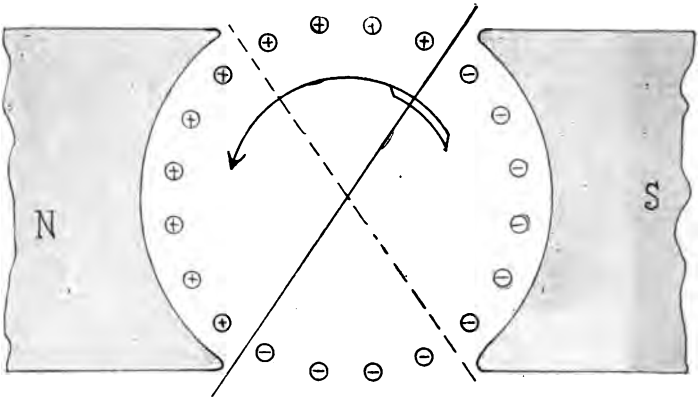


Fig. 180—*The two lines show the relative positions of the commutating planes of a motor and a generator*

Commutation

The process of commutation can be explained by reference to a simplified diagram of the armature winding as shown in Fig. 181. The commutator segments are marked C1, C2, C3, etc., while the various parts of the armature winding called elements and marked 1, 2, 3, etc., are shown connected in series, the terminals of these elements being connected to the commutator segments in regular order. The position of the neutral plane is represented by the line AC, the direction of rotation by the large curved arrow, the direction of the polarity of the part of the pole shown to the right by the letter S; and the current in the various elements of the winding by the small arrows. With the direction of current in the elements of the armature winding corresponding to that shown in the figure, the brush B must be negative in the case of a motor.

As the armature rotates the commutator segments in turn pass under the brush, and if the arc of contact of the brush on the commutator is greater than the width of the insulation between the commutator segments, which always should be the case, then an element of the armature winding will be short-circuited when the brush is in contact with the two segments to which the terminals of the element are connected. When an element becomes short-circuited by the brush it is no longer directly in series with the elements of the armature winding to its right or left, and the current in the element will drop to zero value, provided there is no electromotive force induced in the element, or it is moving parallel to the magnetic field. It does not do so instantly on account of a property of the element, called its inductance, which tends to prolong the

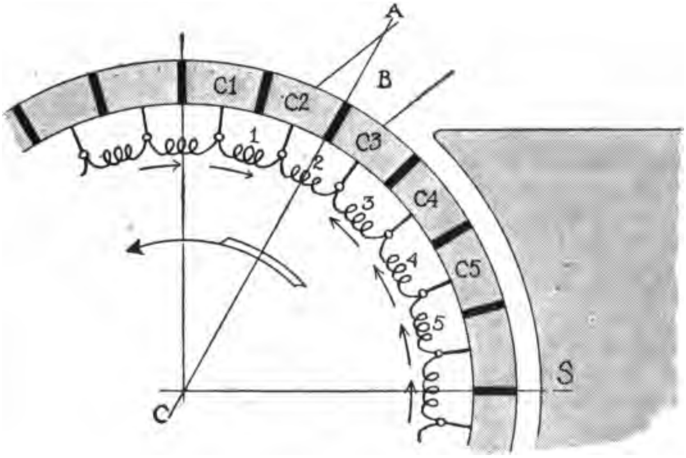


Fig. 181—*Reference to this figure explains the process of commutation. The line AC represents the neutral plane* current. As the armature rotates one of the commutator segments to which the short-circuited element is connected moves out from under the edge of the brush and the short-circuit on the element is removed, and the element becomes a part of the circuit through the armature to the left of the brush. When the element which was short-circuited becomes a part of the left-hand path through the armature, it must carry the same current the other elements in that path carry, regardless of the value of the electromotive force being generated in the element, because they are all directly in series. If the short-circuited element has zero current when the short-circuit is removed by one of the segments moving from under the brush, the current in the element must increase almost instantly to a value equal to the current in the elements in the left-handed circuit through the armature. A property of the element, inductance, opposes this sudden increase in current, and as a result there is a tendency for an arc to form between the edge of the brush and the commutator segment which is breaking contact with the brush until the current in the element whose short-circuit is being removed has reached its proper value, or the inductance of the coil has been overcome. This condition of affairs would result in a continuous sparking at the brushes, which would not only represent a loss but would be injurious to both the commutator and the brushes.

Sparking due to the cause just mentioned can be reduced and practically overcome by moving the brushes back of the neutral plane. When the brushes are thus changed, an electromotive force will be induced in the element of the winding while it is short-circuited, and this electromotive force will be in a direction such as to produce a current in the element in the same direction as the current in the elements to the left of the brush. The induced electromotive force in the element which is short-circuited also causes the current in the element, when it comes into the short-circuited position, to decrease to zero value in a less time than it would if there were no induced electromotive force in the element. The above results, due to the effect of the induced electromotive force in the short-circuited element, indicates that the inductance of the element is overcome while it is short-circuited, and a current of the proper value will be established already in the element when it becomes a part of the left-hand circuit. Moving the brushes back of the neutral plane results in a decrease in the turning effort the armature is capable of producing, but this is more than offset by the advantages of better commutation.

The winding which has been used in explaining commutation is perhaps the simplest form possible, but the fundamental principles involved are practically the same in every case.

In certain types of lap windings the elements are connected to segments which are not adjacent to each other but may be several segments apart. In such a winding, it is necessary that the arc of contact of the brushes cover several segments in order that the various elements may be commutated properly. The time of short-circuit of the different elements must be such that it is possible to reverse the current in the element.

In the case of wave windings, the elements are connected to commutator segments which are approximately 360 electrical degrees apart, and instead of an element being short-circuited by a single brush, as in the lap winding, it is short-circuited by two brushes of the same polarity, these brushes being connected externally by a heavy conductor, called the brush ring.

The brushes on a machine may be adjusted to give practically perfect commutation for a given field current and armature current, but if either the field or the armature current, or both, change in value, there will be a change in the degree to which the resultant magnetic field of the machine is twisted, and, as a result, the commutation will not be as satisfactory as before the change. To have as good commutation as possible at all times, it would be necessary to move the brushes whenever the position of the neutral plane is changed.

Commutation is improved somewhat by increasing the resistance of the short-circuited element, though there is a slight decrease in efficiency, due to the introduction of this resistance in the main armature circuit. When the resistance of the short-circuited element is increased, the current can be reversed in direction in a shorter time than with the lower resistance. Carbon brushes have the advantage of giving better commutation than copper brushes, as they offer a higher resistance in the path of the short-circuited element than the copper brushes do. They are sometimes copper-plated to reduce their resistance in the main circuit of the machine.

Reducing Armature Reaction

Armature reaction interferes with the satisfactory operation of the motor, and it always is desirable to reduce it to a minimum where possible. There are several methods of bringing about a reduction in armature reaction, some of the more important ones being:

(a) By constructing the machine with a relatively long air gap;

(b) By slotting the pole cores parallel to the axis of the armature core;

(c) By properly shaping the pole pieces.

(a) Increasing the length of the air gap increases the reluctance of the magnetic circuit, and more ampere-turns are required to produce the necessary magnetic flux than would be required with a shorter air gap. The effect of the cross ampere-turns on the armature in distorting the magnetic field is not so great when many ampere-turns per pole are required, as it is with fewer ampere-turns per pole. As a result, the position of the neutral plane of the machine remains more nearly constant.

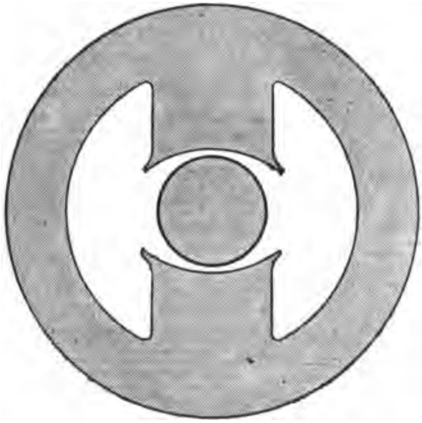


Fig. 182—*Chamfered pole shoes reduce the shifting of the magnetic flux*

(b) Cutting slots in the pole cores parallel to the axis of the armature core introduces a larger reluctance in the path on which the cross magnetizing ampere-turns act but does not introduce anything like as great a reluctance in the main magnetic circuit of the machine.

(c) The shifting of the magnetic flux across the pole shoes of the machine can be reduced readily by shaping the pole faces so that the parts of the air gap where the magnetic flux tends to become most dense will have the greater reluctance. Thus the pole tips may be chamfered, as in Fig. 182, or the bore of the pole faces may be made eccentric with respect to the armature, as in Fig. 183. Additional reluctance at the pole tips may be provided by using a long thin tip or, in the case of laminated poles, by using a stamping of the form shown in Fig. 184, in which case the laminations are built up to the required thickness in such a manner that the projecting tips are on alternate sides. This construction may be used for the pole pieces alone and then bolted to a solid pole core.

Counter-Electromotive Force

When the armature of a motor revolves in the magnetic field of the machine, an electromotive force is induced in the wires on the surface of the armature, called conductors, just the same as there would be if the machine were operated as a generator. Since the relation between the direction of motion of a wire carrying a current when it is placed in a magnetic field and the direction of the magnetic field in the case of a motor is opposite to what it is in the case of a generator, the direction of the current in the wires and the direction of the magnetic field remaining constant, the induced electromotive force in the armature winding of the motor will be just the reverse of what it is in the case of the generator.

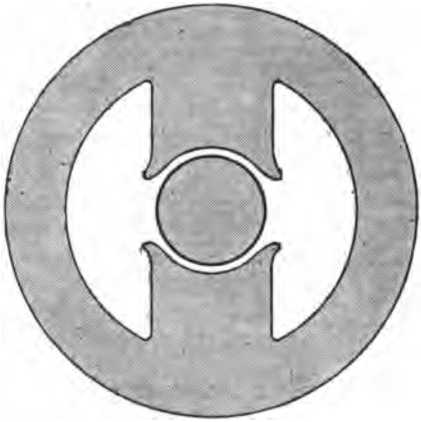


Fig. 183—*Eccentric pole shoes also increase the reluctance at the pole tips*

This induced electromotive force acts in a direction just opposite to the impressed electromotive force which is producing the current in the armature winding, and, for that reason, it is called a counter-electromotive force of the motor. The counter-electromotive force of a motor depends on the same thing on which the generated electrical pressure in a generator depends. It increases with an increase in speed and decreases with a decrease in speed, all other conditions remaining the same. It also increases with an increase in the field strength of the motor and decreases with a decrease in field strength, all other conditions remaining the same.

The counter-electromotive force of a motor under normal conditions cannot exceed in value the voltage of the circuit to which it is connected; just as the voltage of a battery which is being charged cannot rise above the voltage of the circuit to which it is connected. If the electromotive force in the armature of a motor for any reason should exceed the voltage of the circuit to which it is connected, the action in the machine will change from that of a motor to that of a generator and will deliver current to the circuit to which it is connected just as a battery will deliver current to a circuit to which it is connected if the voltage of the battery exceeds the voltage of the circuit and the battery discharges instead of charging. In the motor the electricity is flowing in the opposite direction to the pressure and is doing work, and this work is transformed in the motor from electrical work into mechanical work, a part of which is delivered by the motor to the device it may be operating.

Torque Produced by a Motor

The torque of a motor is its turning effort, which is measured in pound-feet, as explained in one of the early chapters. There are several things on which the torque of a motor depends, but only two of these may be changed after the motor is constructed, namely, the field strength and the armature current. An increase or decrease in the value of either the field strength or armature current or both results in an increase or decrease in the torque. It is obvious from the above statement that the torque of a motor will increase more rapidly when the field strength and armature current are both increasing than it will when either the field strength or armature current are increasing alone.

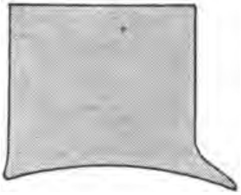


Fig. 184—*The projecting tips of laminated poles are on alternate sides*

Speed of a Motor

The speed of a motor will always be such, when it has reached a constant value, that the torque produced is just ample to drive the load connected to the motor. Since the torque depends on the value of the field strength and the armature current, it is evident that the constant speed at which a motor will operate when driving a certain load will depend on the field strength and the armature current. The armature current taken by a motor will be equal to the voltage of the circuit to which the motor is connected minus the counter-electromotive force generated in the armature of the motor divided by the resistance of the armature circuit. The counter-electromotive force depends on the field strength and the speed.

In general then, the speed of a motor will always be such that the counter-electromotive force generated at that speed will permit the proper amount of current to pass through the armature in order that the torque developed is just ample to drive the load at that particular speed. If the load on the motor should increase for any reason, the torque that is being developed is no longer ample to drive the load or maintain the speed; hence there is a decrease in speed, which results in a decrease in the counter-electromotive force and in turn an increase in armature current and an increase in torque. The speed will continue to decrease and the torque to build up until the torque has increased to a value just ample to drive the increased load. Likewise, should the load on a motor decrease the torque it is developing will be more than is required to drive the load, and as a result there will be an increase in speed. This increase in speed results in an increase in counter-electromotive force, which causes the current to decrease, and hence the torque decreases. The increase in speed will continue until the torque has been reduced to a value just ample to drive the load the motor is connected to.

Output of a Motor

The output of a motor depends on the torque the motor is developing and the speed at which the motor is operating. If the torque be measured in pound-feet and the speed in revolutions per minute, then the output of the motor in horsepower may be determined by the following equation:

$$\text{Output in horsepower} = \frac{6.2832 \times \text{torque} \times \text{revolutions per minute}}{33{,}000}$$

It is evident from the above equation that the horsepower the motor is delivering will vary directly as the torque if the speed remains constant and directly as the speed if the torque remains constant.

Operation of the Shunt Motor

The connections of a shunt motor are shown diagrammatically in Fig. 185. In this particular case the motor is arranged to be operated from a three-cell storage battery. When the switch S is closed a current whose value will depend on the voltage of the battery and the resistance of the field circuit will be established in the field winding and at the same time a current will be established in the armature circuit. The current in the armature will react on the magnetic field produced by the field current, and a torque will be produced, which will cause the armature to rotate unless the load on the motor happens to require a greater driving torque than the motor is capable of producing. Assuming the torque the motor is producing is ample to start the load, then the speed will increase, which causes the counter-electromotive force to increase, it being zero in value while the armature is standing still, and as a result there will be a decrease in the current in the armature and hence a decrease in the torque developed.

The speed will continue to increase and the torque to decrease until the torque developed is just ample to drive the load at the particular speed it is then operating. Any change in load on the motor will mean a change in the torque the motor is required to develop, and hence a change in speed will take place and the current in the armature will adjust itself to the required value to produce the desired torque. With an increase in load there will be a decrease in speed, but this decrease, in the ordinary shunt motor, ordinarily will not amount to a great deal in percent of the motor's rated speed, as a very small decrease in speed will result in the necessary decrease in counter-electromotive force. As a rule the counter-electromotive force differs from the impressed voltage acting on the motor by a very small amount.

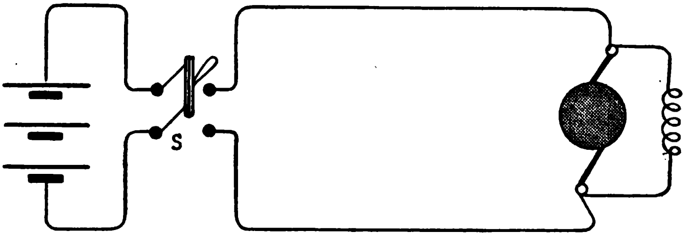


Fig. 185—*Shunt motor connected to a three-cell battery*

The relation between torque and armature current and speed and armature current may be represented graphically, as shown in Fig. 188. If the field strength of the motor were to remain constant the torque would increase directly as the armature current. Since there is a weakening of the magnetic field, due to armature reaction and other causes, the torque will not increase quite as rapidly as the current, and this increase will grow less and less rapid as the current increases in value, which accounts for the curve in the figure, marked torque, not being a straight line.

The speed of the shunt motor decreases with an increase in current in order that there be the proper reduction in counter-electromotive force so that the current may increase and thus produce a greater torque.

Operation of the Series Motor

The connections of a series motor are shown diagrammatically in Fig. 186. When the switch S is closed a current will be produced by the battery in the armature and field circuits in series. The value of this current, at the instant the circuit is closed, will be equal to the voltage of the battery divided by the total resistance of the circuit, and it will have its maximum possible value, since no counter pressure is generated in the armature of the motor when it is standing still. This large current will produce a very strong magnetic field, and hence a maximum torque will be developed. This torque will cause the armature to rotate, unless the torque required to drive the load exceeds that of the motor, and just as soon as the armature starts to rotate a counter-electromotive force will be generated, which will cause a decrease in armature current and hence a decrease in torque. When the torque has decreased to a value just ample to drive the load at the speed at which it is then operating, the speed of the motor will become constant. As the motor speeds up there is a decrease in torque, due to a decrease in armature current and also due to a decrease in field strength. If the load on the motor is decreased,

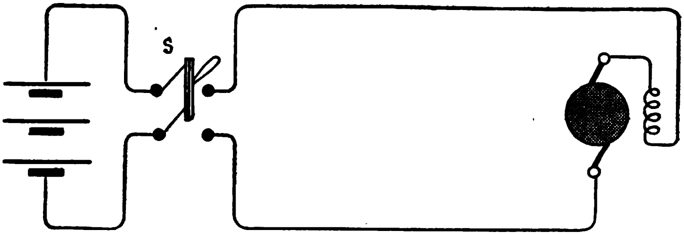


Fig. 186—*Series motor connected to a three-cell battery* the torque the motor is developing is more than ample to drive the load, and it immediately starts to increase in speed. The increase in speed means an increase in counter-electromotive force and a decrease in armature and field current. The decreasing field current causes the field strength to grow less, which tends to lower the counter-electromotive force. This tendency of the decreasing field strength to lower the counter-electromotive force in effect does not amount to as much as the increase in speed, which results in the counter-electromotive force increasing. The increase, however, is not as much as would take place, due to a given change in speed, if the field strength remained unchanged. Hence, in order to bring about the required increase in counter-electromotive force with a decrease in load on the series motor there will be a greater increase in speed than in the case of the shunt motor.

The relation between speed and armature current for a series motor is shown in Fig. 187. When the load is removed entirely from a series motor the only torque it is required to develop is that necessary to revolve the armature. This small torque means a small armature and field current is required. The small field current means a very weak field, and the speed will be high in order that the proper counter-electromotive force be generated by revolving the armature in the weak field. In some cases this speed may become dangerously high, and for this very reason it is not advisable to try to operate a series motor when it is disconnected from a load.

The torque of a series motor increases more rapidly as the current in the armature increases than it does in the shunt motor. The reason for this is due to the fact that the field strength is increasing at the same time the armature current is increasing. The relation between torque and current is shown by the curve marked torque in Fig. 187. The characteristics of the series motor as pointed out above are such that it is much better adapted to the requirements of a motor to be used in starting the gasoline engine than the shunt motor.

Compound Motor

The compound motor is a combination of the series and shunt. When the magnetizing action of the series field opposes the magnetizing action of the shunt field the machine is called a differential compound motor. When the magnetizing action of the two fields act in the same direction the machine is called a cumulative compound motor.

In the case of the differential compound motor, the field strength is weakened as the current the motor takes increases and as a result there is not as much of a decrease in speed in order that the counter-electromotive force decrease to the required value as there would be if the field strength remained constant. It is possible in such a motor to maintain the speed practically constant for all load currents by properly adjusting the magnetizing effect of the series fields. The torque of a differential motor does not increase as rapidly with an increase in armature current as it would if the field remained constant in strength.

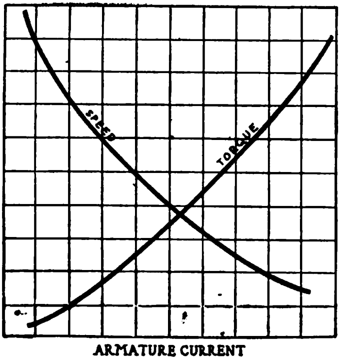


Fig. 187—*Relation of torque and speed to armature current for a series motor is represented here*

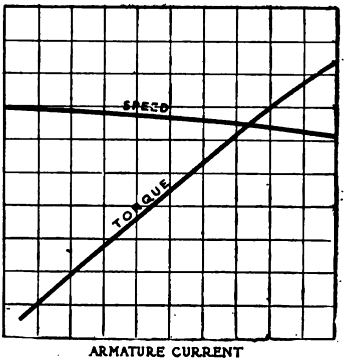


Fig. 188—*These curves show relation of torque and speed to armature current for a shunt motor*

The characteristics of the cumulative compound motor are between those of the shunt and series motor, it being a combination of the two so far as the magnetizing action of the field windings are concerned.

Starting Motors

When the armature of a motor is connected directly to the source of pressure a current whose value is equal to the pressure divided by the resistance of the circuit will be produced. In some cases this current is excessive, and in such cases it is necessary to connect a variable resistance in series with the armature. As soon as the armature starts to rotate a counter-electromotive force will be generated, which causes the current to decrease in value, and the resistance may be decreased in value and finally removed from the circuit. Such a device is called a starting box, but it is used little with motor car motors, as the motors usually are designed to carry the maximum current the battery will send through them when the armature is at a standstill.

Motor-Generator

The motor-generator is a combination of a motor and a generator, mechanically connected together and usually mounted on a common metal or wooden base. The motor of such a combination may be either a direct-current or an alternating-current motor, and it may be constructed to operate on any reasonable value of voltage, depending on the particular requirements. Likewise, the generator may be one capable of delivering either direct-current or alternating current, and this current may be delivered at almost any voltage, depending on the requirements, which determine the construction of the generator. When the two machines are coupled directly together by a flexible coupling their speed will be the same. If a belt or gear is used in connecting them, their speeds may be the same or different, depending on the size of the pulleys or gears used. The electrical operation of the motor is entirely independent of the generator. The field of either machine may be varied in strength without changing the field of the other machine.

A combination of two machines forming a motor-generator set is shown in Fig. 189. A motor-generator outfit may be used in changing alternating current at one voltage into direct current at some other voltage or vice versa, or it may be used in increasing or decreasing alternating or direct-current voltage. For example, suppose only alternating current is available and you wish to charge storage batteries. The motor element of your motor-generator should be an alternating-current motor of such a construction and voltage that it will operate on the alternating-current circuit from which you are to obtain the electrical energy. The generator element should be of such a construction that it will deliver the required current and at the proper voltage. The horse-power capacity of the motor always should be such that it will drive the generator when the generator is delivering its full load.

In some cases direct-current is available but at such a voltage that it cannot be used economically in charging storage batteries unless the batteries be connected in series, which is quite inconvenient and often times impossible. In such cases it often results in a large saving to install a motor-generator set composed of two direct-current machines, the motor being constructed to operate on the voltage available and the generator to deliver current at the proper voltage to charge the batteries. Remember that the output of the generator in watts would be equal to the input to the motor in watts if there were no losses in the machines. That is, if the voltage of the generator is less than the voltage of the motor, then the current the generator will deliver will be greater than the current taken to operate the motor. On account of losses in the two machines the output of the generator is always less than the input to the motor.

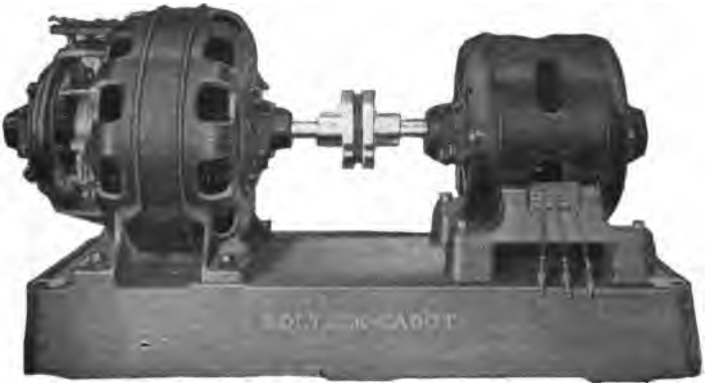


Fig. 189—*This motor generator consists of an alternating-current motor, left, which drives a direct-current generator, right*

Dynamotor

The dynamotor is a machine having an armature with two windings and provided with two commutators which may be mounted on the same or opposite ends of the armature. Both of these windings revolve in the same magnetic field, and any change in the strength of the magnetic field will influence the value of the voltage generated in both windings. The voltage generated in the two windings will be the same if there are the same number of turns about the armature in each of the windings. If the number of turns in the two windings are unequal the voltages generated in the two windings will bear the same relation to each other as exists between the number of turns, the winding of larger number of turns having the greater voltage induced in it.

Both of these windings may be used to deliver current; that is, both windings will act as generators when the armature of the machine is driven in some way as by a motor or gas engine.

One winding may be used as a motor and drive the other winding in the magnetic field, and it will act as a generator and may deliver current. The voltage at which the generator winding will deliver current depends on the ratio between the number of turns in the two windings and the voltage applied to the motor winding, neglecting voltage losses in the two windings. This voltage relation is fixed by the relation of the turns in the two windings and cannot be changed by varying the strength of the magnetic field as in the case of the motor generator for the following reasons:

If the field of the dynamotor be increased in strength in an attempt to increase the voltage generated in the generator winding, there will be a decrease in speed of the armature, as the necessary counter-electromotive force now will be generated in the motor winding at a lower speed since the field strength has been increased. This decrease in speed of the armature counteracts the effect of the increase in field strength so far as the generator winding is concerned, which results in the voltage generated in the generator winding remaining practically constant. If the voltage applied to the motor winding be increased or decreased there will be a proportionate increase or decrease in the voltage produced in the generator winding. The fixed voltage relation in the dynamotor is its chief disadvantage when used in charging storage batteries, as the current sent through the battery must be adjusted by a series resistance rather than by varying the field of the generator as in the case of the motor generator.

The Dynamotor as a Starting and Lighting Unit

The dynamotor is used by several different companies in place of a separate generator and motor. The electrical and mechanical connections of the machine are such that the generator and motor actions are taking place at different times. A good practical example of the use of the dynamotor is found in the Delco system shown in Fig. 190. The terminals of the two sets of windings are brought out at opposite ends of the armature and connected to separate commutators. A diagram of the two windings is given in Fig. 191. There are nineteen segments in the commutator of the motor and just twice as many, or thirty-eight, in the commutator of the generator. These windings are placed in the same slots in the armature core. The magnetic field of the machine is produced by either a shunt or series coil, depending on whether the machine is acting normally as a generator or as a motor. The operation of the Delco dynamotor may be divided into three distinct parts, and these are:

(a) Motoring the generator.
(b) Cranking the engine.
(c) Generating electrical energy.

Before discussing each of the above operations it will be best to explain what changes in connections take place when the ignition switch is closed and the starting pedal is pressed down. Closing the ignition switch connects the generator armature winding and shunt field across the terminals of the storage battery. As the starting switch is pressed down one of the brushes on the commutator of the motor, which normally is raised from the surface of the commutator, is lowered; a switch in series with the armature of the generator is opened; and the gears used in cranking the engine are thrown in mesh. See Fig. 192.

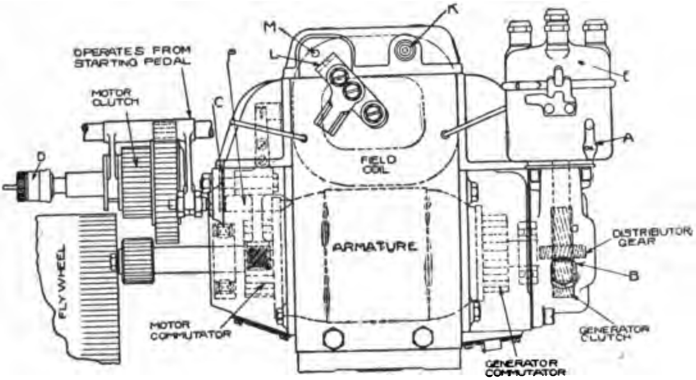


Fig. 190—*Side view of Delco dynamotor, which usually is called a motor generator*

(a) When the armature and field of the generator are connected to the battery by closing the ignition switch a motor action takes place in the generator armature winding, and the armature starts to revolve. The connection between the shaft of the dynamotor and the engine is made by a form of over-running clutch which only transmits power when the shaft driven by the engine tends to run at a greater speed than the shaft of the dynamotor. This clutch, called the generator over-running clutch, allows the armature of the dynamotor to revolve freely, when the engine is standing still, in the same direction as it is rotated by the engine when the dynamotor is being operated as a generator.

(b) The motoring of the generator assists in bringing the gears into mesh when the starting pedal is pressed down. Lowering the brush on the commutator of the motor closes the motor circuit, which is composed of the motor armature winding and series field connected in series to the battery. At the same time, the motor action in the armature of the generator is stopped as the generator switch is opened. The dynamotor now is operating as a series motor and driving the engine. As soon as the engine starts to fire the motor will cease to transmit power to the engine, as a second over-running clutch in one of the gears allows the speed of the shaft driven by the engine to exceed the speed of the shaft of the dynamotor. The starting pedal now should be released, which raises the motor brush and closes the generator circuit.

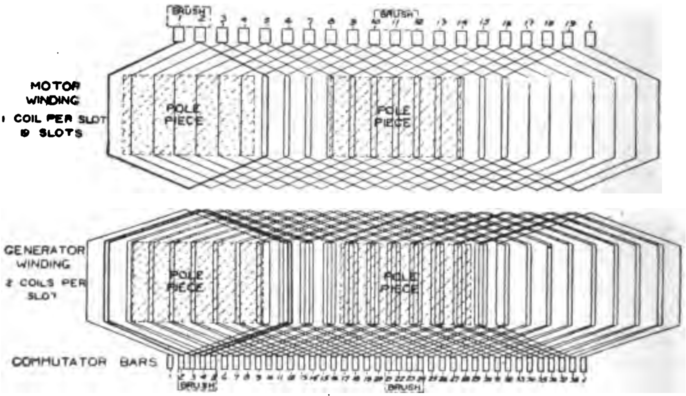


Fig. 191—*Comparison of motor and generator windings on Delco dynamotor*

(c) As soon as the engine speeds up power will be transmitted to the dynamotor through the generator over-running clutch. If the generator switch is closed a generator action will take place in the generator armature winding, provided the voltage in this winding exceeds the voltage of the battery to which the brushes of the generator are connected. When the voltage in the generator armature winding drops below the voltage of the battery, due to any cause, the generator will be changed to a motor, and power may be transmitted to the engine through the motor over-running clutch. A more complete description of this and other similar systems will be given later when the various complete systems are discussed in detail.

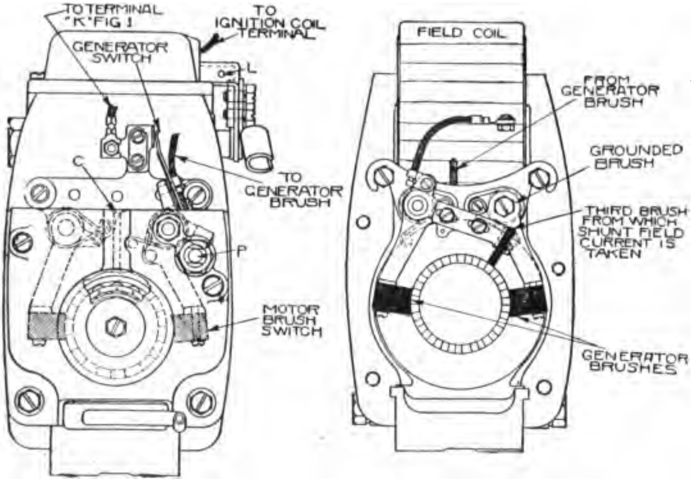


Fig. 192—*End views of Delco dynamotor*

CHAPTER XVII

Motor and Engine Connection

General Requirements of Starting Motor

THE chief function of the starting motor is to turn the gasoline engine over at such a speed that it may be started readily, assuming the position and intensity of the spark, as well as the gas mixture and all other conditions under which the starting motor must be capable of operating the engine, in the majority of cases is between 100 and 200 r.p.m. If the starting motor is connected to the engine in such a manner that it must operate at the same speed as the engine, it is evident that it must be capable of developing sufficient torque so that the torque available at the gear or pulley on its shaft is just equal to that required to drive the engine at the desired speed.

On the other hand, if the connection between the motor and engine be made in such a manner that the motor may run much faster in r.p.m. than the engine, the torque the motor must be capable of producing at the gear or pulley on its shaft will bear, neglecting losses, the same relation to the torque required to drive the engine as the speed of the engine bears to the speed of the motor.

For example, if a certain engine requires a torque of 20 pound feet to drive it at a speed of 150 r.p.m. and the starting motor is geared to the engine in such a manner that it operates at forty times the speed of the engine, then the torque the motor must be capable of delivering at its gear or pulley will be, neglecting losses, equal to one 1/40 of 20 or .5 pound feet. The losses between the gear on the motor shaft and the shaft of the engine must be taken care of by the motor in addition to driving the engine; that is, the actual torque of the motor will always be greater than the theoretical torque required, due to these losses. The losses in some gear types of transmissions may amount to as much as 40 per cent, while the manufacturers of certain types of chain transmissions claim the losses are as low as 5 per cent.

The size of an electric motor capable of delivering a certain horsepower depends on the speed at which the motor is to be operated, there being an increase in size with a decrease in speed and, conversely, a decrease in size with an increase in speed. On account of the limitations in size of the starting motor, due to space and weight requirements, it is obvious that it would be better to have the speed at which the motor operates greater than the speed of the engine. There are several exceptions to this last statement, and the principal ones are found in the U.S.L. outfit, the Woods dual power car and the Owen Magnetic, all of which will be explained in detail later.

The main requirement of the connection between the electric motor and the engine is to provide a positive mechanical connection so that the power developed by the motor may be transmitted to the crankshaft of the engine. This mechanical connection is required only when the motor is driving the engine, and the construction and operation of the intermediate device should be such that power may be transmitted in one direction only. This can be explained better by assuming a definite case.

Suppose the ratio between motor and engine speeds in a certain installation is 30 to 1 and that the motor will operate the engine at 125 r.p.m. When the engine starts to fire, it is operating at approximately 125 r.p.m. and the motor is operating at 3,750 r.p.m. The speed of the engine will increase, and when it reaches a speed of 500 r.p.m. the speed of the motor will be 15,000, which is considerably above the safety limit, and the motor should be disconnected from the engine long before this speed has been reached.

Several different devices are employed to overcome the above difficulty, such as the ordinary jaw clutch similar to that employed on all hand cranks, friction clutch, roller overrunning clutch, ratchet-and-pawl overrunning clutch, worm-and-worm-wheel, Bendix drive, electromagnetic-operated pinions, mechanically-operated pinions, etc.

Overrunning Jaw Clutch

A type of clutch similar to that used in connecting the starting crank to the crankshaft of a motor first was used in connecting the starting motor to the engine. This clutch consists of a number of jaws on two opposite surfaces with their backs beveled and arranged so that they will mesh with each other; but power can be transmitted in one direction only, as the jaws will slide past each other when the portion of the clutch being driven tends to exceed the speed of the driving portion. This type is little used, due principally to the fact that it gives a clicking noise when the engine runs away from the starting motor, as it will do immediately after each piston has passed its position of maximum compression.

An example of the application of a clutch of this type is shown in Figs. 193, 194 and 195. When the upper end of the clutch actuator is moved toward the right the left-hand portion of the clutch shown in Fig. 193 will move along the end of the crankshaft, and the teeth become engaged with the teeth on the surface of the large sprocket. This sprocket turns freely on the end of the crankshaft when the clutch is disengaged, being driven by a chain which runs over a second and smaller sprocket mounted on a shaft as shown in Fig. 194, which in turn is driven by the starting motor through a worm-and-worm gear as shown in Fig. 195. As long as the large sprocket in Fig. 193 tends to turn faster

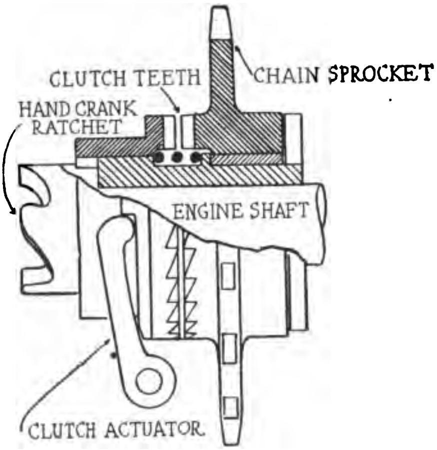


Fig. 193—*Type of clutch first used in connecting starting motor to engine*

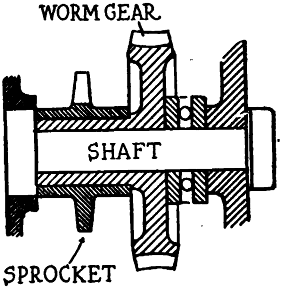


Fig. 194—*A further detail of the same clutch. It is little used* in a clockwise direction as viewed from the left-hand end, or front, of the engine than the left-hand part of the clutch, the two portions of the clutch will remain engaged, but just as soon as the speed of the engine exceeds that of the large sprocket the clutch becomes disengaged and the two surfaces move relative to each other, giving a clicking sound.

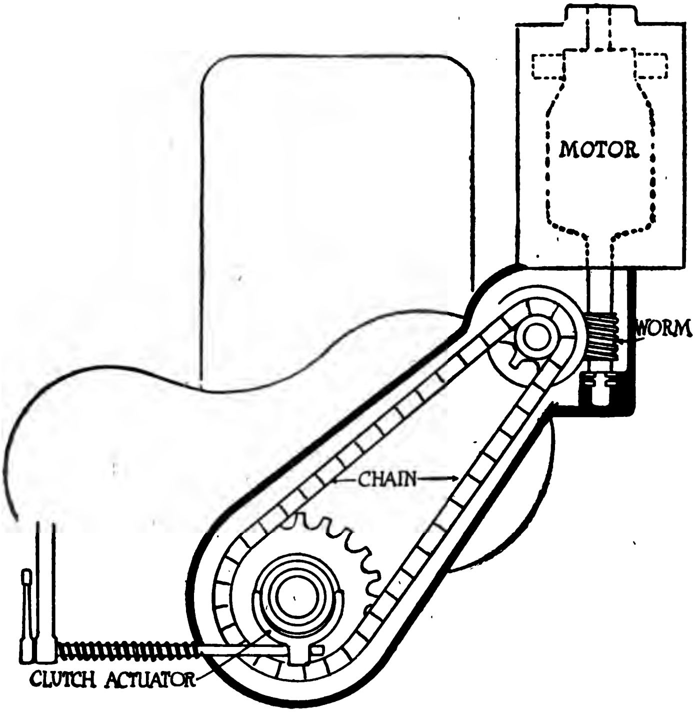


Fig. 195—*The motor turns the sprocket through the worm-and-worm gear. When the engine runs away from the motor the clutch gives a clicking noise*

Overrunning Roller Clutch

There are several different forms of roller clutches, but in principle they are the same. For this reason a typical form, such as the one used by Gray & Davis, will be described. The construction of the clutch is shown in Fig. 196, and it consists of two principal parts, the outer ring B and the clutch center C. The outer portion of the clutch may be driven by gears, chain drive, or it may be connected rigidly to the driving shaft. In this particular case power is transmitted to R by the pinion P, and it is arranged to drive the inner portion C in a clockwise direction. Several slots are cut in the outer surface of the portion C, four in this particular case, and the depth of these slots varies from one side to the other, being deeper on the right-hand side of each slot when the slot is in its uppermost position.

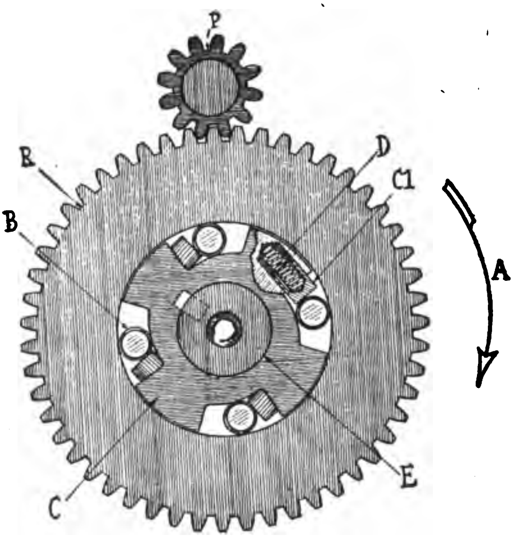


Fig. 196—This illustrates the principle of the overrunning roller type clutch

Rollers are placed in these slots as shown at B with their axis parallel to the axis of rotation of the clutch—that is, the rollers are parallel to the shaft E—and they are held away from the deeper side of the slot by a suitable plunger, C, and spring, D. The diameter of these rollers is a little greater than the depth of the slots on their shallow side, and as a result the springs cannot force the rollers completely over against the side of the slots. When the outer ring R of the clutch is rotated in the direction of the arrow A the rollers will be wedged between the inner surface of the ring R and the bottom of the slots. With the rollers thus wedged tightly between the two parts of the clutch, the inner part C will be rotated in the same direction and at the same speed as the outer portion R, and power may be transmitted from R to C, which in turn may be connected through gears, chain or direct, to the crankshaft of the engine. In this particular case the inner portion of the clutch is keyed to the shaft E.

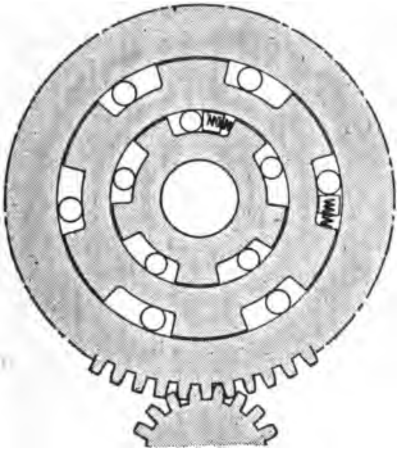


Fig. 197—*The double overrunning roller type clutch used by the Northeast company*

Just as soon as the starting motor starts to revolve the pinion P the outer portion of the clutch will start to revolve, and the locking action just described will take place between the two parts R and C almost instantly, which results in the cranking action taking place at once. The cranking action of the motor will continue until the engine starts to fire, when its speed will increase. This results in the speed of the inner portion of the clutch exceeding the speed of the outer portion, and the two parts no longer will be locked together, as the rollers then will tend to roll into the deeper part of the slots, due to the fact that the piece C is traveling faster than the inner surface of the piece R, and the direction in which the rollers turn about their own axis will be just the reverse of what it was when the piece R tended to turn faster than the piece C. The starting motor is now running idle and may be stopped without interfering in any way with the operation of the engine.

In some cases a double overrunning clutch is employed as shown diagrammatically in Fig. 197. With a double combination of this kind the machine may be operated at one speed when acting as a motor and driving the engine and at another speed when it is being driven by the engine and acting as a generator.

Overrunning Ratchet-and-Pawl Clutch

The operation of the overrunning ratchet-and-pawl type of clutch may be understood easily by reference to Fig. 198. Four pawls are attached to a plate, which in turn is fastened to the crankshaft or shaft that is to be driven. These four pawls engage teeth cut in the inner periphery of a ring which is the driving portion of the clutch. One, or perhaps two, of the pawls will be engaged with the teeth when the engine is at rest, due to the action of their counterweights. The two pawls marked A and B are engaged at the position shown in Fig. 198. Power is transmitted from the starting motor through the outer portion, or ring, to the plate on which the pawls are mounted as long as any one of the pawls is engaged with the teeth. Just as soon, however, as the speed of the plate exceeds that of the ring the pawls are dis-

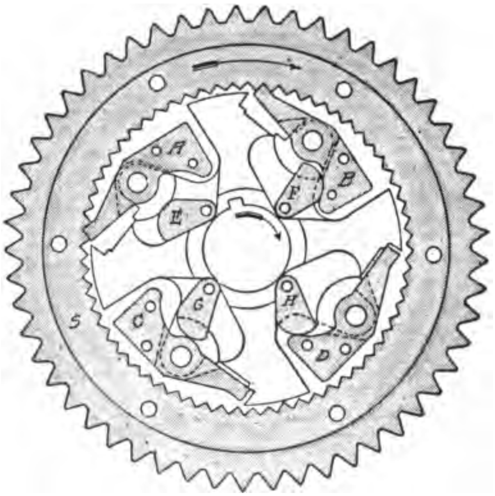


Fig. 198—The operation of the overrunning ratchet and pawl type of clutch is explained by reference to this drawing

engaged and held away from the teeth by the centrifugal force acting on their counterweight. To prevent the pawls from suddenly re-engaging when the engine comes to a stop and rocks back and forth, a second set of pawls is provided, and they are shown at E, F, G and H in the figure. When the clutch is inoperative or idle all this second set of four pawls fall into their lowest position. Just as soon as the plate on which they are mounted rotates they are thrown out to a radial position, as shown by the position of the one marked H. If the plate happens to start to revolve in the opposite direction, the inertia of the four smaller pawls throws them into the position shown by the one marked G, which prevents the main pawls engaging the teeth. When the plate on which the pawls are mounted comes to a complete stop at least one of the main pawls will fall into a correct position for starting.

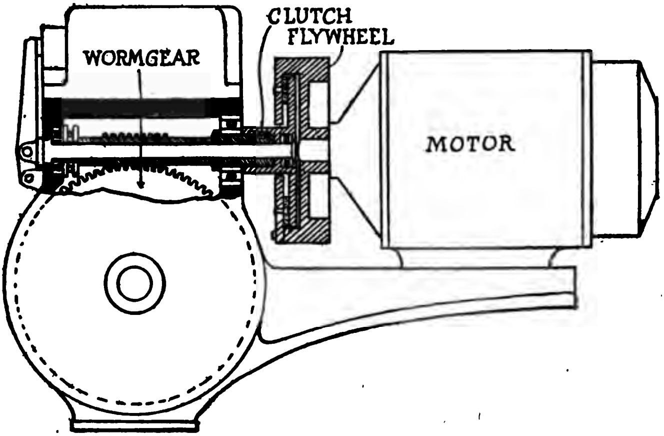


Fig. 199—*Friction clutch and worm-and-worm gear which connects Hartford starting motor to the engine*

Friction Clutch

The Hartford starting motor is connected to the engine by a friction clutch and worm-and-worm gear as shown in Fig. 199. When the starting switch pedal is depressed the electrical connection between the motor and battery is completed, and at the same time a strong pull is produced on the lever attached to the end of the rod P, which transmits a strong pull on the friction clutch mounted in the flywheel of the motor and thus connects the motor to the engine.

Non-Automatic Pinion Shift

The fundamental principle of the non-automatic pinion shift is shown in Fig. 200. When the switch rod is moved to the starting position it operates the switch and connects the motor to the battery and at the same time causes the sliding pinion to become engaged with the gear on the flywheel. The overrunning clutch mounted in the intermediate gears prevents the engine from running the starting motor at an excessive speed. Just as soon as the switch rod is restored to its normal position both the starting switch and sliding pinion are restored to their normal position.

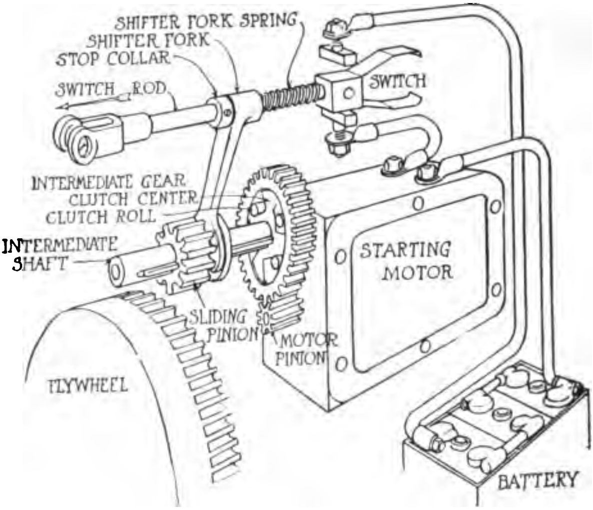


Fig. 200—Drawing to illustrate fundamental principle of the non-automatic pinion shift

Another good example of the non-automatic pinion shift is found in certain installations of the Westinghouse Electric & Mfg.

Co., shown diagrammatically in Fig. 201. In the non-automatic mechanical pinion shift of the Westinghouse company, a starting pedal is mounted on the foot-board, or a lever is mounted conveniently for hand operation. The operation of the system thus controlled can best be understood by reference to Fig. 201. The contact-making part of the switch is shown in this diagram mounted on the gear-shift rod.

At A is the "off" position of the shift pinion and switch contactor. Pressure on the starting lever moves the shift rod first

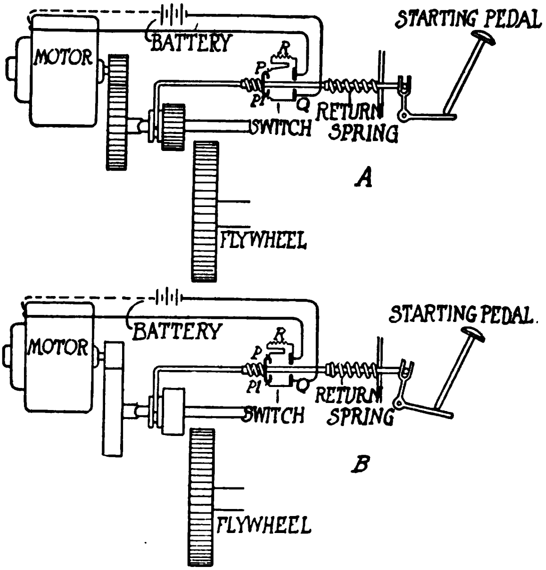


Fig. 201—Westinghouse system—A gives the "off" position of the shift pinion and switch contactor; in B the motor circuit is closed and the motor starts at low speed

to the position shown in B, closing the motor circuit at P and P_1 through the resistance R; this starts the motor at low speed. Further motion of the shift rod to position C opens the electric circuit, but the motor and pinion continue to turn, owing to their momentum. When the position C is reached, the pinion still is turning slowly so that it cannot fail to mesh with the gear; but as power is turned off the motor, there is no difficulty in sliding the teeth into full engagement. As soon as the teeth do engage, further foot pressure on the starting lever shifts the rod to the position shown in D, closing the electric circuit at Q after the pinion and gear have meshed a sufficient distance to present a good bearing length on the teeth. This connects the motor directly to the storage battery so that full power is impressed, turns over the engine until the starting lever is released or the engine picks up on its own power. There is an over-running clutch between the flywheel pinion and the motor, so that if the pedal is not promptly released when the engine picks up, the motor is not driven by the engine. When the pressure is removed from the starting lever, the shifting-rod springs return all parts to position A. This re-

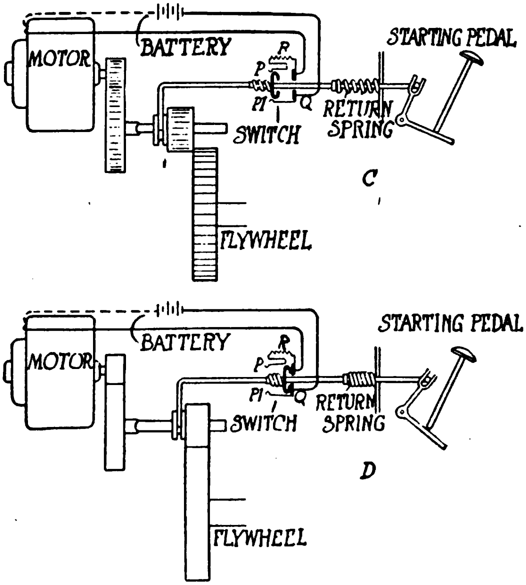


Fig. 201—*At C the teeth can be slid into full engagement, after which the motor connects directly with the storage battery and the engine is turned over, D* leases the gears and opens the electric circuit, and the motor comes to rest.

The pinion is meshed with the gear on the flywheel in the

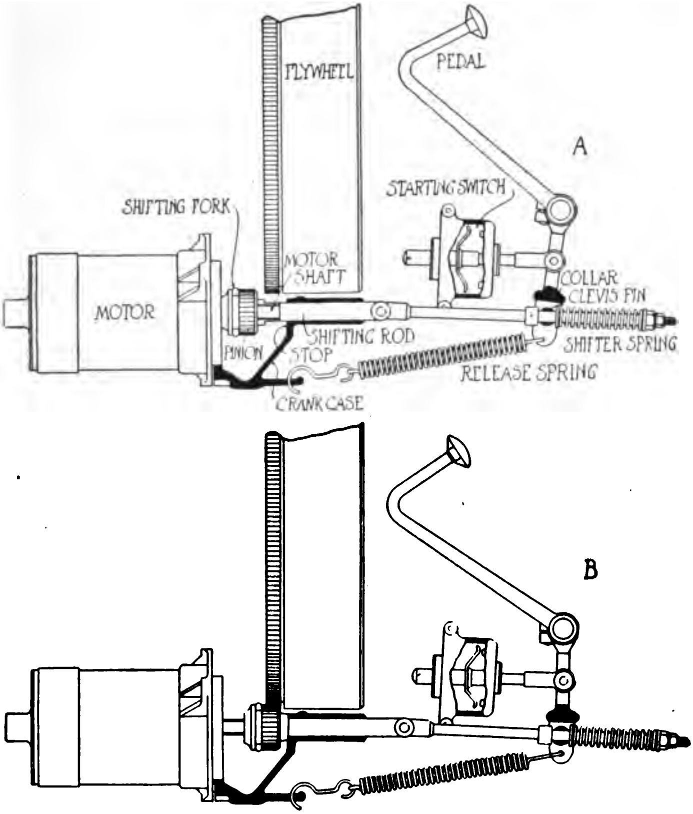


Fig. 202—*Bijur system—as applied to the* 1916 *Hupmobile —A, out of action, starting switch off, pinion against motor head; B, about to crank, gears have meshed, but switch has not made contact*

Bijur system as applied to the Hupp motor car by pressing the starting pedal, and by a further movement the starting switch is closed. Four stages in the operation of starting the engine are shown in Fig. 202. No overrunning clutch of any kind is used in this particular system, and for this reason the motor should be disconnected from the flywheel just as soon as possible after the engine starts to fire.

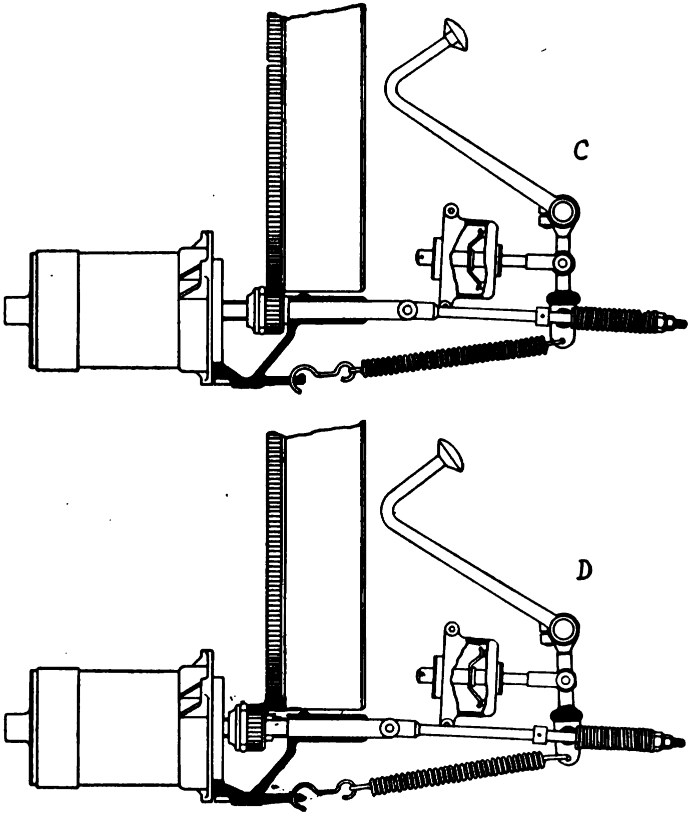


Fig. 202—C, cranking, note cap between collar on shifting rod and clevis pin—shifting fork is against stop, and shifter spring is compressed slightly. D, about to crank, when gears are not meshed, teeth are butting but switch has made contact. Shifter spring is compressed strongly, ready to draw pinion into mesh

Automatic Electromagnetic Pinion Shift

The starting motors the Westinghouse Electric & Mfg. Co. used in this application are composed of three principal parts; the stationary parts, or field; the rotating parts, or armature and shaft; and the shifting magnet. The armature is mounted on a hollow shaft; on the end of this shaft is mounted a splined pinion which drives the engine flywheel. The pinion is made to slide along the shaft by a shifting rod which is attached to the pinion and passes through the hollow shaft. The other end of this shifting rod acts as the core of the shifting magnet. When the motor is not revolving, a return spring holds the pinion at the end of the shaft and clear of the flywheel gear.

As shown diagrammatically in Fig. 203, when the starting switch is closed a circuit is complete from the negative terminal of the battery through the switch, the shifting magnet, the armature and the series field of the motor to the frame of the car and through this to the positive terminal of the battery. The motors used in this application are of the series type; that is, the field is connected in series with the armature so that all the current flowing through the one also flows through the other. One of the characteristics of this kind of motor is that the amount of current flowing through it is proportional to the amount of energy it develops.

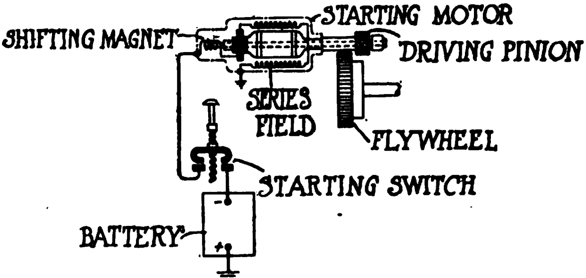


Fig. 203—Here the closing of the starting switch completes a circuit between the terminals of the switch

When the starting switch is closed, current flows through the circuit as noted above, causing the armature and shaft and the pinion to rotate. The motor requires a high current at the instant it starts from rest. This high current, through the shifting magnet, energizes it sufficiently to overcome the force of the return spring and therefore draws the shifting rod through the shaft, thus sliding the pinion into mesh with the gears on the flywheel. The teeth on the flywheel and the pinion are cut diagonally so that they mesh very easily. As soon as the pinion meshes with the flywheel gear, the current required to turn the engine over is enough to hold the pinion in mesh until the engine fires. When the engine picks up it soon runs at higher speed than that of the motor.

When the engine speeds up so that its speed approaches the no-load speed of the motor, the current in the latter falls off so that the pull of the shifting magnet is less than that of the return spring, which therefore throws the pinion to its original position clear of the flywheel. The motor will continue to revolve, without load, however, until the starting switch is opened or released; but the pinion remains out of mesh, because the current required to turn over the motor is not enough to energize the shifting magnet sufficiently to pull the pinion back into mesh against the force of the return spring.

Bendix Drive, or Automatic Pinion Shift

The Bendix drive consists of a solid or hollow shaft having screw threads on the outside and a hollow gear having screw threads on the inside, so that the gear screws on the shaft like a nut on a bolt. A circular weight is fastened to the gear and is slightly out of balance. A coil spring connects the electric motor shaft and the hollow screw shaft. The relation of these various parts is shown in Fig. 204.

When the electric motor starts, it drives through the spring and turns the screw shaft. Because of the weight the gear is too heavy to turn with the screw shaft, and because the gear does not turn it must move along the screw shaft, just the same as if you turned a bolt having a nut on it and kept holding the nut with your fingers to keep it from turning so that it would be screwed along the bolt. After the screw gear has moved along the screw shaft and engages with the flywheel gear, it then keeps on moving along until it reaches the stop at the end of the screw shaft. The two gears then are fully meshed, and when the screw gear has reached the stop it must turn with the screw shaft. At this moment the screw shaft and electric motor are revolving at a great speed, and this great blow and the power of the electric motor both are taken through the coil spring. The spring keeps coiling until all this power has been applied to the flywheel gear and the engine starts turning.

As soon as the engine starts exploding and runs under its own power, the flywheel turns much faster than when it was cranked by the starter. Because it is now turning so much faster it increases the speed of the screw gear, so that the latter runs faster than the screw shaft on which it is mounted. Therefore, when the screw gear runs faster than the screw shaft, it is screwed on the threads of the shaft, like a nut on a bolt, until it has been screwed out of mesh with the flywheel gear. This de-meshing movement is entirely automatic and eliminates the use of an over-running clutch. Now that the screw gear is out of mesh, it is natural to suppose that if the electric motor keeps running, the gear automatically will be screwed right back into mesh with the flywheel gear. But the unbalanced weight on the screw gear now performs its automatic function, that is, being slightly out of balance, the weight twists or cocks the screw gear so that it clutches and binds on the screw shaft and turns with it. This automatic clutching is due to the centrifugal force of the unbalanced weight. When the electric motor stops running the screw gear has been fully screwed away from the flywheel gear, and it remains in that retarded position until it is required to start the engine.

The gear on the screw shaft has an automatic self-cleaning action, but, in any extreme case, should the gear tend to stick on the shaft, through being covered with mud, it may be necessary to clean the screw.

The teeth on the screw gear and flywheel are chamfered, or pointed, on only one side to make the meshing natural and easy. However, should the teeth meet, end to end, the screw shaft itself is designed to move backward automatically and compress the coil spring. This gives the screw gear time enough to turn and enter the flywheel gear. Should sticking of gears ever occur, they can be released by throwing in the clutch and moving the car. Such trouble would be due to incorrect chamfering or inaccurate alignment of the gears. Also it might be due to the binding of the drive parts and prevent compressing and proper functioning.

If, while the engine is running, the electric motor should be started accidentally, the screw gear will screw over against the turning flywheel gear. But instead of the clashing and smashing

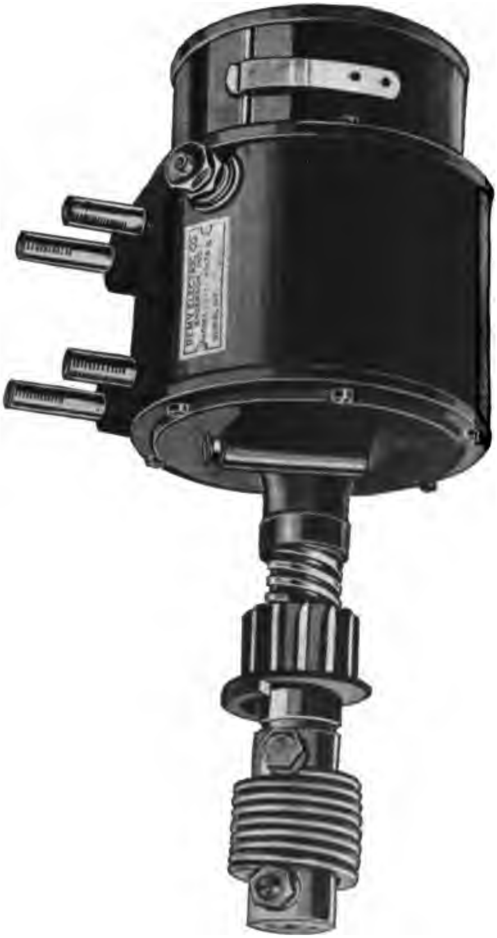


Fig. 204—Bendix drive, or automatic pinion shift, showing the relation of the various parts as applied to Remy motor

of gears that might be expected there is no danger whatever, as the gears simply touch once. This is because the flywheel gear will speed up the screw gear, and thus automatically screw it away. The turning screw gear will then automatically clutch and bind on the screw shaft, in exactly the same manner as when it is cranking and has been de-meshed when the engine starts exploding.

Old Bosch-Rushmore Electromagnetic Drive

The starter drive used on the old Rushmore system, which was acquired by the Bosch Magneto Co., and later known as the Bosch-Rushmore system, is a feature of the later Bosch products

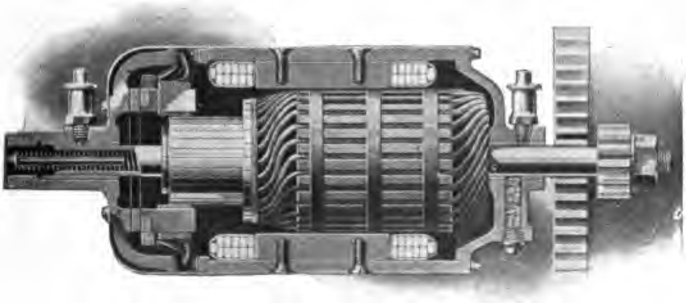


Fig. 205—*Sectional view of old Bosch-Rushmore starter. It is still a feature of Bosch products but has been improved decidedly*

with decided improvements. The old Rushmore drive is illustrated and described herewith. The Bosch improvements will be taken up later.

The construction of the Bosch-Rushmore motor is such that the armature can be shifted endwise in its bearings. In the non-operating position the armature is held out of its electrical center or, in other words, out of line with the pole shoes, by a spiral spring in the commutator end of the armature shaft; therefore, when in the normal position, the pinion on the driving shaft of the starting motor is out of mesh with the gear ring on the flywheel of the engine. A sectional view of the motor is shown in Fig. 205.

The motor is provided regularly with three terminals, two of which are heavier, or of larger diameter, than the other. The two heavier terminals are for the main circuit, and the single small terminal is for the shunt circuit.

During the first part of the downward movement of the switch pedal an electrical circuit is established, which causes the current from the battery to pass through the switch shunt. The amount of current that can flow is limited by the resistance of the circuit, but of the current which passes through the switch shunt a small portion is allowed to flow through the motor armature, while the greater portion flows through the motor field coils, forming thereof a strong electromagnet. See diagrams of electrical circuits as given in Figs. 206 and 207. The result is a powerful attraction between the field coils and the armature, causing the latter to be drawn endwise into the magnetic center of the motor or, in other words, into its working position between the pole shoes. The passing of the small current through the armature causes the armature to rotate slowly, and as the rotary motion occurs simultaneously with the shifting of the armature endwise, the meshing of the motor pinion with the gear ring on the engine flywheel is accomplished quickly and positively.

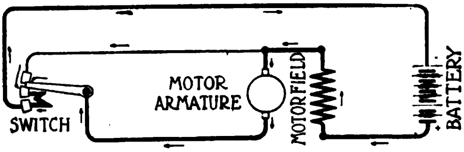


Fig. 206—*Electrical circuit of Bosch system with switch pedal in first part of downward movement*

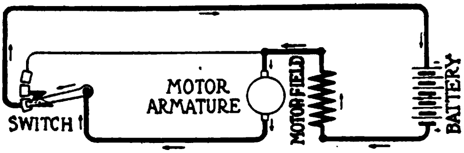


Fig. 207—*Here the switch pedal has completed the downward movement and the engine turns over*

As the switch pedal reaches its limit of motion the flow of battery current through the switch shunt, as well as that through the shunt cable to the field coils, is interrupted, and a straight series motor connection is established, allowing the entire current to pass through the motor field and armature windings and causing the engine to turn over until it starts firing. Although it takes time to explain this series of actions, the entire operation takes place so rapidly that the impression on the observer is that the motor pinion slips into place and begins turning the engine flywheel immediately after the starting switch pedal is depressed.

As soon as the engine starts the starting motor is relieved of its load, and the current passing through it drops rapidly in volume, this being a characteristic of series motors. In consequence, the strength of the field magnets is lessened to a point where the spiral spring in the end of the armature shaft overcomes the magnetic attraction holding the armature and returns it to the original, or non-operating, position. It is this action that automatically and positively throws the armature shaft pinion out of mesh with the flywheel gear ring. Thereafter, until the starting switch is released, any current which continues to pass through the armature merely will cause the latter to revolve freely but without meshing with the flywheel, due to the fact that the amount of current utilized when the motor is running free is not sufficient to overcome the tension of the spiral spring. The non-operating position of the armature is shown in Fig. 208 and the operating position in Fig. 209.

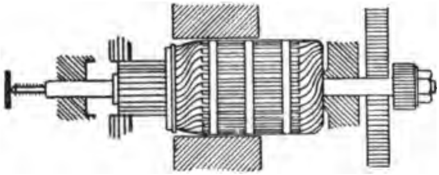


Fig. 208—Armature of Bosch starting motor in non-operating position

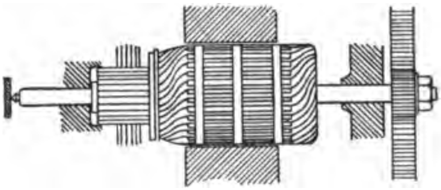


Fig. 209—Armature of Bosch starting motor in operating position

Direct Application of Starting Motor

The combined motor and generator used in the system manufactured by the United States Light & Heating Co. differs from any of the other systems which are designed primarily for starting and lighting systems in that the device is incorporated in the flywheel housing, and the revolving part is mounted directly on the end of the engine crank shaft without any reduction gears or chains of any kind. The component parts of the system are shown in Fig. 210. A section through an assembled system is shown in Fig. 211, in which the parts shown in shaded areas are to be furnished by the U. S. L. company and parts shown in white, or section, are to be furnished by the manufacturer of the car. The field is of the multipolar construction and it is held rigidly in position by bolts in the front of the flywheel compartment. The armature, or rotor, is

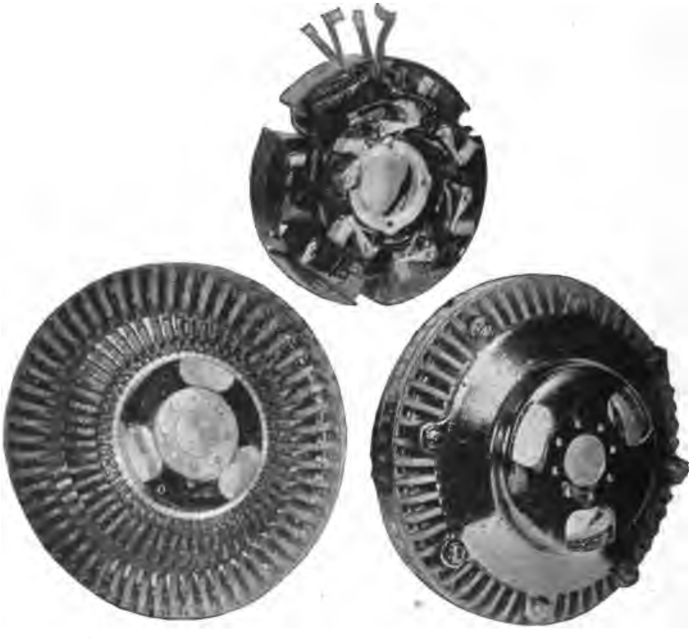


Fig. 210—*Component parts of U. S. L. system. A combined motor and generator is used in this system* mounted on a special flange fastened to the back end of the engine crankshaft, and it revolves outside the field structure. In some types of U. S. L. systems the armature revolves inside the field structure.

Back-Kick Releases

The object of a back-kick release is to take care of any excessive strain which may be put on the device used in connecting the motor to the engine. If the spark lever be too far advanced, there will be a premature explosion, which will tend to rotate the motor in the opposite direction to that in which it is running and thus subject the connecting device to a very severe strain. The power of the motor is ample to overcome this strain in the majority of cases, and the connecting devices are designed with this abnormal condition in mind, and as a result the necessity of any special device is not nearly so great as it might at first appear.

A device used by the Northeast company consists of a friction clutch which is held in contact by springs. This clutch will not slip under ordinary and reasonable loads, but should the load become unusually excessive it will slip and thus protect the remainder of the connecting equipment between the motor and the generator.

A friction clutch is used on the Hartford starter on account of the irreversible worm-and-worm gear drive used, as the teeth of the gear would more than likely be damaged in case the engine backfired.

A brake band is sometimes used in combination with the starting gears, and this band is held tight, in such a manner that it holds and transmits power in one direction only.

Location of Starting Motors

A number of different possible locations of the starting motor with reference to the engine and transmission are shown in Fig. 212.

The shaft of the motor, as shown at 1, is at right angles to the crankshaft of the engine and usually is connected to the crankshaft by a worm-and-worm gear alone or a worm-and-worm gear in combination with a second gear or chain. An example of

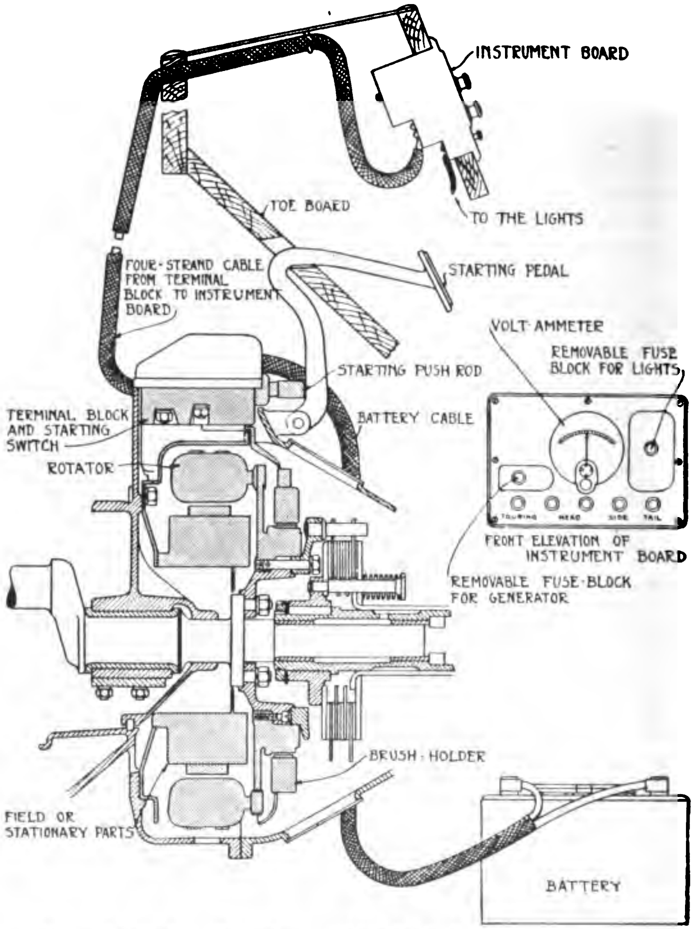

INSTRUMENT BOARD
TO THE LIGHTS
TOE BOARD
FOUR-STRAND CABLE FROM TERMINAL BLOCK TO INSTRUMENT BOARD
STARTING PEDAL
VOLT-AMMETER
REMOVABLE FUSE BLOCK FOR LIGHTS
STARTING PUSH ROD
BATTERY CABLE
TERMINAL BLOCK AND STARTING SWITCH
ROTATOR
TOURING
HEAD
SIDE
TAIL
FRONT ELEVATION OF INSTRUMENT BOARD
REMOVABLE FUSE-BLOCK FOR GENERATOR
BRUSH-HOLDER
FIELD OR STATIONARY PARTS
BATTERY

Fig. 211—Section through assembled U. S. L. system. The parts shown in white are furnished by the maker of the car; those in shaded areas, by the U. S. L. company

the location of the motor in which the connection is by a worm-and-worm gear was shown in Fig. 199.

The motor may be located alongside the engine as shown at 2 in Fig. 212 and connected to the crankshaft by gears or a chain or perhaps a combination of the two. An example of this location of the motor in which the connection is made by a chain is shown in Fig. 213. Installation of a double-deck arrangement of motor and generator in the Saxon four is shown in Fig. 214.

The starting motor may be mounted in front of the flywheel as shown at 4 in Fig. 212 or it may be located behind the flywheel as shown at 5 in the same figure. In the majority of cases the connection is direct between the pinion on the motor and a gear cut in the surface of the flywheel or in a collar which is mounted on the rim of the flywheel. In some cases a chain or gear reduction is introduced between the motor shaft and the gear on the flywheel. The pinion on the driving shaft may be made to engage the gear on the flywheel by any one of the several methods previously described. The installation of the Bijur system on the Packard is shown in Fig. 215.

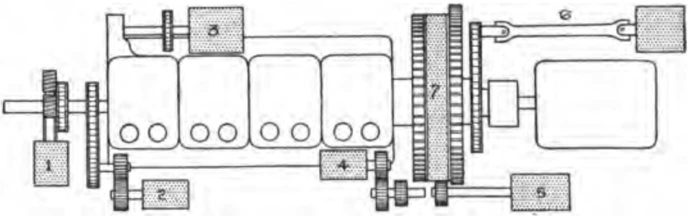


Fig. 212—Diagram to illustrate possibilities of starting motor location with reference to the engine and transmission

The application of the Bosch flywheel starter to the Marmon is shown in Fig. 216. The pinion in this system is made to mesh with the gear on the flywheel by moving the shaft on which the pinion is mounted endwise. This movement is produced by the magnetic pull of the field of the motor on its armature which is normally off center with respect to the field as shown in section in Fig. 205.

The installation of a Westinghouse starting motor on the Chalmers six is shown in Fig. 217. The motor in this installation is mounted on the gear case and a bearing is provided in the flywheel case for the end of the shaft on which the pinion is mounted.

A representative starting motor as made by the Delco company for direct flywheel drive is shown in Fig. 218.

The method of connecting the motor, shown at 6 in Fig. 212, is decidedly different from any of the other methods thus far described in that it is connected to the transmission shaft, and power is transmitted from the motor to the engine through the friction clutch in the flywheel. An installation of this kind is found on the Reo car, it being manufactured by the Remy company.

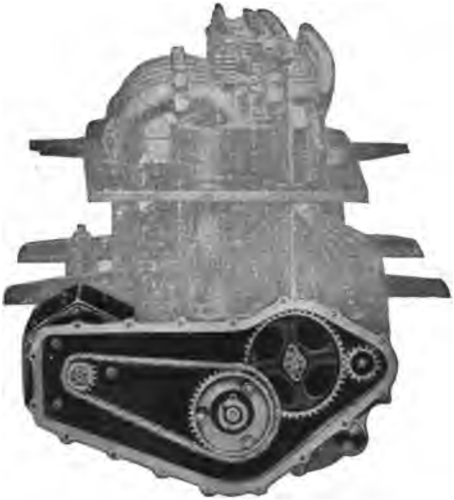


Fig. 213—Application of dynamotor made by the Dyneto company to the Franklin cngine

The only example of the motor installation shown at 7 in Fig. 212 in which the electrical unit is installed for starting and generating purposes alone is that of the U. S. L. system. An example of the complete installation of this system is shown in Fig. 219.

Purpose of Generator Drive

The function of the generator is to provide a suitable means of charging the storage battery while it is installed on the motor

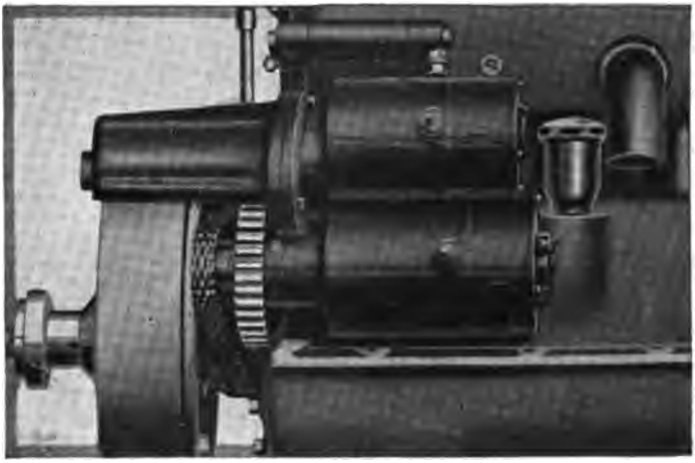


Fig 214—Installation of double-deck arrangement of motor and generator in the Saxon four

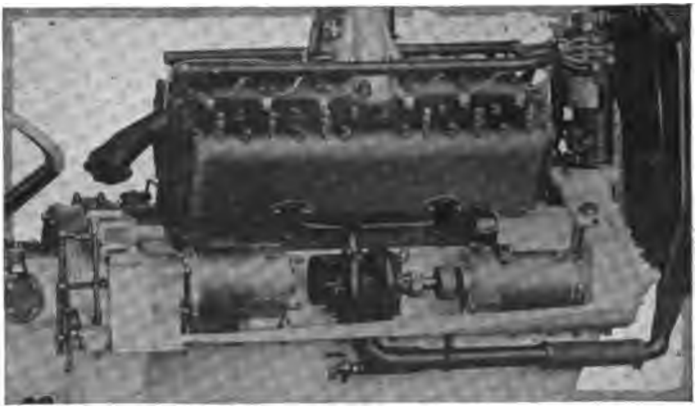


Fig. 215—Installation of Bijur system on the Packard

car, thus keeping the battery practically completely charged at all times so that an ample supply of energy is always available for operating the starting motor, lamps, horn and other electrical

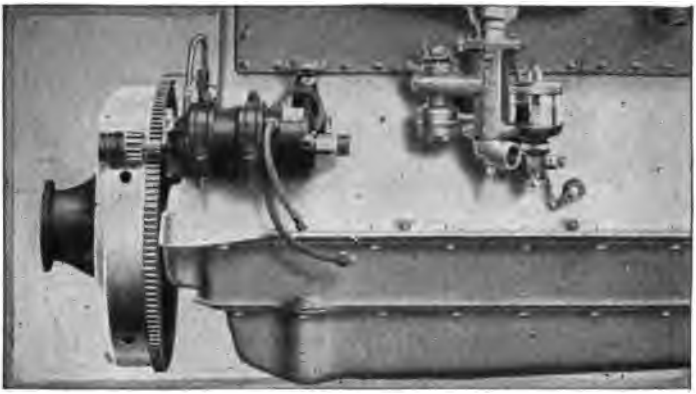


Fig. 216—*Application of the Bosch flywheel starter to the Marmon*

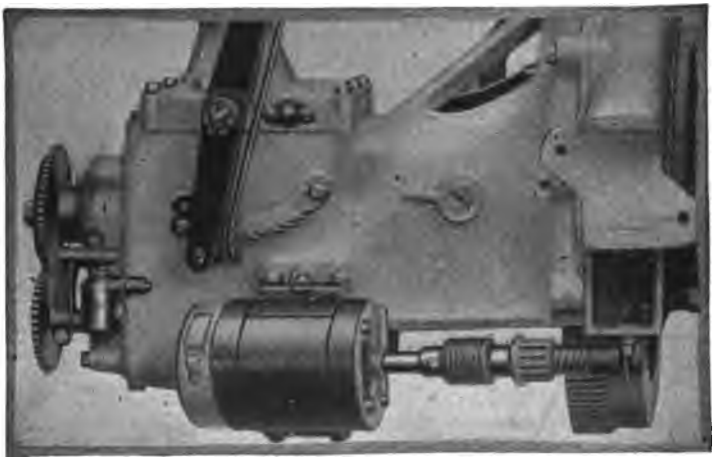


Fig. 217—*Installation of a Westinghouse starting motor on the Chalmers six*

devices which may be installed originally on the car. In no case should additional electrical equipment be installed upon any car unless you are reasonably sure the capacity of the storage battery is ample to take care of the additional load and at the same time the capacity of the generator is sufficient to keep the battery charged under normal operating conditions.

The generator will not start to charge the storage battery until the electrical pressure generated in its armature is greater in value than the electrical pressure of the battery. The electrical pressure generated in the armature winding of the generator depends on the speed at which the generator is driven, and it will vary directly as the speed at which the armature is revolved if all the other quantities on which the pressure depends, such as the strength of the magnetic field of the machine, etc., remain constant in value. It is obvious, since the electrical pressure in the armature of the generator depends on the speed, that the battery would discharge back through the generator, if they were permanently connected together, when the speed of the generator happened to be of such a value that the electrical pressure of the generator was less than the pressure of the battery. The function of the cutout is to provide a means of disconnecting the battery from the generator when the battery starts to discharge back through the generator. As explained in

Fig. 218—*Delco motor for attachment to flywheel case—a representative two-unit type* one of the previous chapters, these cutouts assume several different forms, some being operated electrically and some by hand.

In order that the electrical pressure in the armature winding of the generator may increase in value as the engine speeds up and the generator starts charging the battery, it is necessary that some mechanical connection be established between the crankshaft of the engine and the armature shaft of the generator. The requirements of this connection are quite different from those imposed on the mechanical connection between the starting motor and the crankshaft of the engine. First of all, the torque required to drive the generator when it is delivering its rated or normal full load will be nothing like as great as the torque the starting motor must develop when it is turning the engine over in starting; hence, the mechanical strains to which the generator connections are subjected will as a rule be less than those imposed on the motor connections. Second, the design and operation of the motor connection in the majority of cases must be such that the motor will be disconnected from the engine crankshaft when the engine starts to fire either automatically or by

Fig. 219—*Complete installation of U. S. L. dynamotor* some manual means. No such requirements need be met in the case of the generator connection, and they are connected in almost every case permanently to the crankshaft of the engine. In some cases, such as in the installation of the Delco dynamotor, a double mechanical connection is provided, but its construction is such that only one connection is operative at any one time as will be explained later. Third, the ratio between the speed of the generator shaft and the crankshaft of the engine, except in the case of dynamotors with a single drive, is quite different from the ratio between the speed of the motor shaft and the crankshaft of the engine. This difference is due chiefly to the fact that the generator will be connected to the engine all the time and, of course, will have to operate under a wider total variation in engine speed than the starting motor.

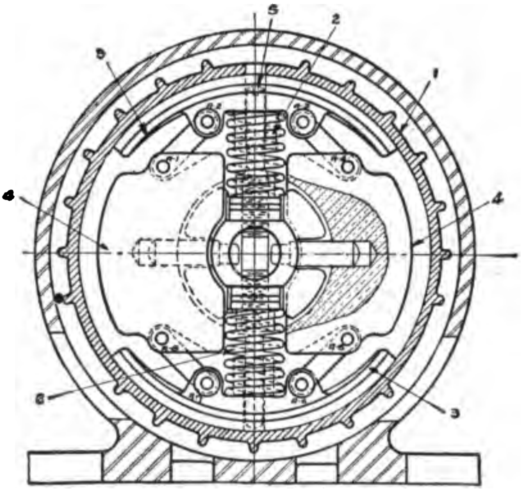


Fig. 220—Sectional view of one form of Gray & Davis friction drive, perpendicular to armature shaft

If the same relation between engine and generator speed were provided as in the case of the motor, the speed of the generator would exceed the allowable limit, and it would be almost impossible to construct an armature and commutator that would withstand continuously the enormous centrifugal forces that would exist at these very high speeds. In the connection of a dynamotor to the engine by a single drive, the gear ratio will have to be lower than the maximum ratio with a double drive to keep the maximum speed down. Fourth, in some cases the ignition distributor is combined with the generator and driven through a gear connection from the generator shaft. In such cases it is absolutely imperative that the position of the distributor arm in relation to the proper firing order of the various cylinders remain fixed at all times, and in such cases it is obvious that the connection between the generator and the engine must be very definite.

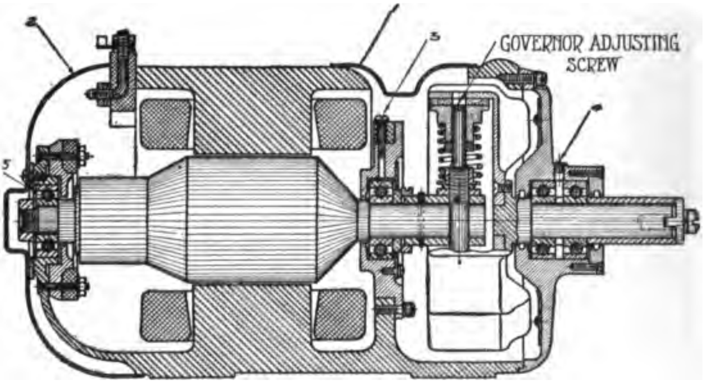


Fig. 221—Sectional view of another form of Gray & Davis friction drive, parallel to armature

Generator connections may be divided into the following main groups and a brief description of one or more typical examples of each kind will be given:

Friction drive.
Belt drive.
Chain drive.
Gear drive.
Mounted directly on engine shaft.

Friction Drive for Generator

A sectional view of the friction drive as used by Gray & Davis on their types E and G-1 generators is shown in Fig. 220, and a sectional view parallel to the shaft of the generator is shown in Fig. 221. The cup-shaped piece of metal marked 1 in both figures is connected to the end of the driving shaft. Two friction shoes, marked 3, are connected mechanically to the end of the generator shaft, so that they may move in or out along pins in the end of the shaft, and are held against the inside surface of the cup 1 by coiled springs, 2, which are under compression. Two weights, marked 4, are connected mechanically by four links to the friction shoes. These weights may move perpendicularly to the shaft along pins fastened to the shaft which enter holes in the weights.

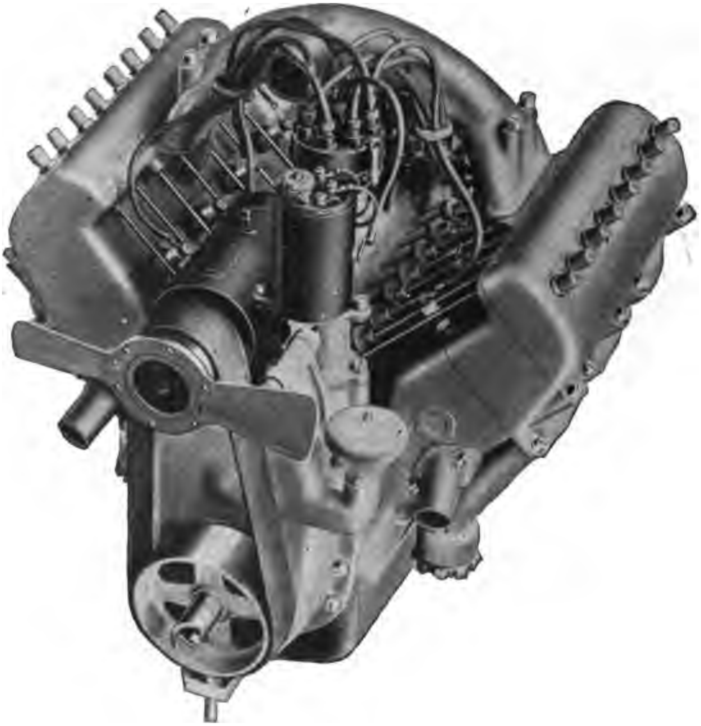


Fig. 222—Belt-driven generator as installed on a Ferro eight-cylinder engine

As the speed of the driving shaft increases, the centrifugal force acting on the weights increases, and this action tends to draw the two friction clutches away from the inside surface of the cup and thus disconnect the generator shaft from the driving shaft. In the majority of cases, when the generator is driven, the speed of the generator shaft at which the disconnection actually takes place will depend on the adjustment of the two coil springs holding the weights against the inside of the cup.

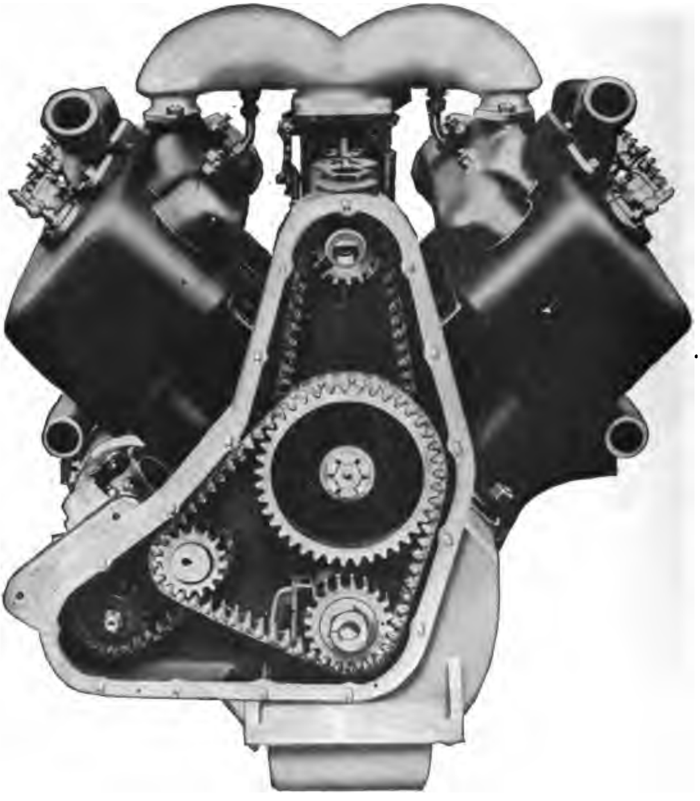


Fig. 223—Chain drive in which the chain is inclosed as installed on a Colonial eight

These springs may be adjusted by inserting a small screw driver in the opening 5. When the maximum current output of the generator is to be increased, which amounts to increasing the speed at which the generator shaft is connected from the driving shaft,

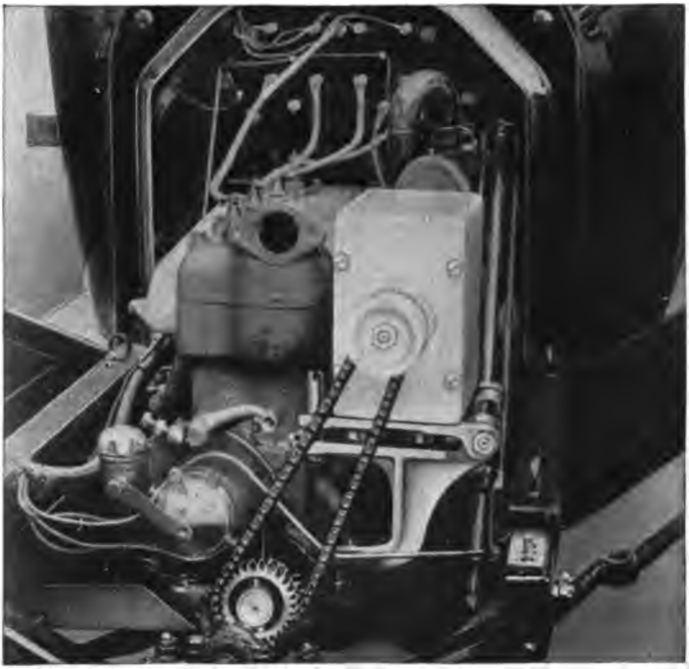


Fig. 224—A Splitdorf-Apelco dynamotor as originally installed in a Ford, showing a chain drive in which the chain is exposed

the screw in the opening 5 should be turned to the right. The governor is very sensitive, and only a slight movement of this adjusting screw is necessary to produce a decided difference in the output of the generator. Just as soon as the speed of the generator decreases a slight amount after the friction shoes are raised from contact with the inside surface of the cup, the centrifugal force acting on the weights will decrease, and the springs will shove the shoes out against the cup and again establish the mechanical connection between the generator and the driving shaft. The total variation in the speed of the generator, when the speed of the driving shaft exceeds the speed for which the generator is adjusted, does not amount to very much, and as a result the electrical pressure generated in the armature winding will rise to a certain maximum value and then remain practically constant for all higher engine speeds.

The small projections around the outer surface of the cup 1 produce a fan-like action which causes a circulation of air through the generator, thus tending to keep its temperature lower than it would otherwise be.

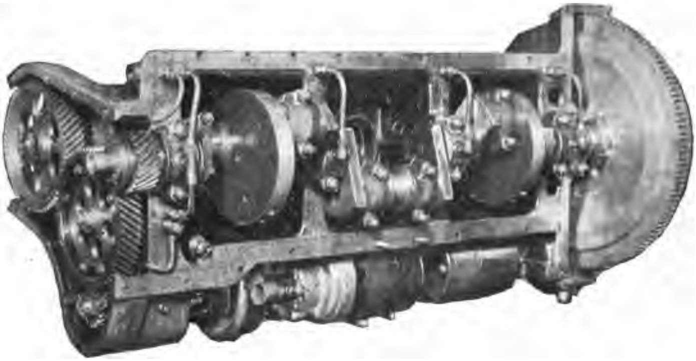


Fig. 225—Installation of gear-driven generator on the Amalgamated engine

Belt Drive for Generator

The generator may be driven by a small belt which runs over a small pulley connected directly on the engine shaft, or the pulley may be connected to the pump or timing gear shaft. In some cases the belt used in operating the cooling fan for the engine is increased in length and made to travel around a small pulley mounted on the end of the generator shaft. Care must be exercised in this particular type of drive to be sure that the belt is always tight enough to prevent an undue amount of slipping. Some special means usually is provided for taking up a reasonable amount of slack in the belt by moving one of the pulleys over which the belt runs or providing an idle pulley whose position may be changed as conditions demand. An example of a belt drive is shown in Fig. 222, which depicts a belt-driven generator as installed on a Ferro eight-cylinder engine.

Chain Drive for Charging Generator

The chain drive has several advantages not possessed by the belt drive, and some of the more important ones are as follows: A positive connection between the generator and the engine at all times; no stretching and hence no special attention is necessary to keep it in adjustment; it may be inclosed and thus better protected and at the same time easily lubricated. Such a drive is the short chain at the left of Fig. 223, which is a Colonial eight.

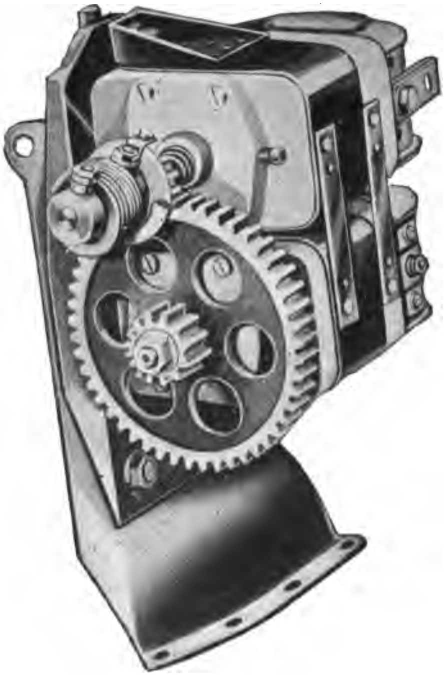


Fig. 226—*Gearing of Gray & Davis **double** unit outfit for the Ford*

All chain drives, however, are not inclosed, especially the earlier installations. An example of a chain drive in which the chain is exposed is shown in Fig. 224, which depicts a Splitdorf-Apelco dynamotor as originally installed on a Ford car.

Gear Drive for Charging Generators

The gear drive provides, as in the case of the chain drive, a positive connection between the generator and the engine crankshaft. In the majority of cases, when the generator is driven by gears, use is made of the timing or pump gears and the generator directly connected to the end of a shaft on which these gears are mounted or to one of the shafts through a gear mounted on the generator shaft. The installation of a gear-driven generator on a new engine design is shown in Fig. 225. The small gear at the bottom is on the generator drive shaft.

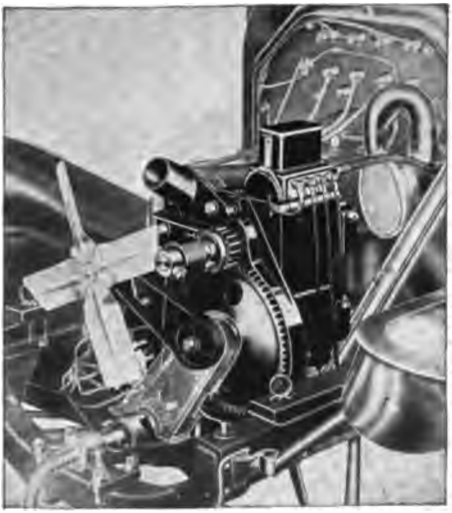


Fig. 227—Heinze equipment for Ford, in which the primary drive is by chain

Mounted Directly on Engine Shaft

The best example of this particular type of installation is that of the U.S.L. system in which the generator and motor are combined in a single unit and mounted in the fly-wheel housing in place of the flywheel itself.

Combined Generator and Motor Drives

The generator and motor drives may be one and the same drive. In some cases there are two drives between the dynamotor and the engine, the gear ratio of the two being different. One of these drives will transmit power from the dynamotor to the engine while the armature of the dynamotor tends to run, due to a motor action, ahead of the engine and is used in starting the engine. The other drive will transmit power from the engine to the dynamotor when the engine tends to run ahead of the armature of the dynamotor. In some cases a part of the connection will be used in transmitting power from the armature of the dynamotor and also in transmitting power in the opposite direction. In such a case an intermediate gear or sprocket is connected to the shaft of the dynamotor through a double roller clutch a part of which will drive in one direction and the other part in the opposite direction. An example of this type is shown in Fig. 226, which shows the gearing of the Gray & Davis double unit outfit for the Ford. The armatures are connected by a large gear and Bendix pinion. The latter becomes inoperative when the motor circuit is opened. A similar installation in which the primary drive is by chain is the Heinze equipment for Fords illustrated in Fig. 227.

Gear Housings

Gear housings are of numerous, different forms, ranging from a very open or exposed type to the completely inclosed type. In some cases this housing is provided by the engine manufacturer with the definite requirements of a particular starting and lighting system in mind, and in such cases the completed installation has a very compact and finished appearance. In other cases the gear housings are provided by the manufacturer of the electrical equipment and so designed that they may be readily mounted on the engine. No general rule is followed in this connection, which results in a very wide variation in the appearance and construction of the various different systems. An example of an inclosed type of motor, or generator, gear housing is shown in Fig. 228.

Gear Reductions

There are quite a number of different methods of bringing about the proper speed relation between the motor and generator and the engine. This may be accomplished by a belt, by chain alone or in combination with gears, by a worm-and-worm gear, by the ordinary spur gear, by a planetary gear, etc.

A gear reduction in which the gearing is supplied by the manufacturer of the electrical equipment is shown in Fig. 229.

The gear reduction shown in Fig. 230 is used by the Westinghouse Electrical & Mfg. Co. The small pinion on the end of the armature shaft meshes with three gears mounted on studs carried on a plate, which in turn is mounted on a shaft extending through the end of the motor housing. The three gears also mesh with teeth cut on the inside surface of the motor housing as shown in the figure. When the pinion on the end of the motor shaft rotates it causes the three gears to rotate and they in turn travel around the inside of the motor housing, carrying the plate on which they are mounted with them, and hence the shaft extending through the motor housing will rotate, but at a much lower speed than the shaft of the motor.

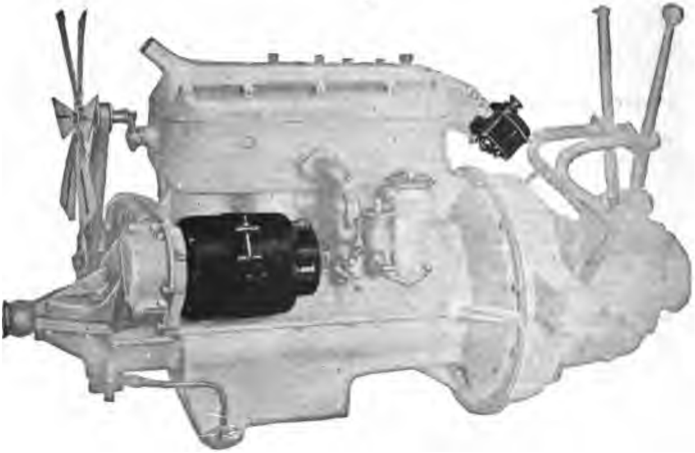


Fig. 228—Inclosed gear housing as used with the North East system on a Dodge Bros. car

A somewhat similar construction to the preceding is employed by the Wagner company, and an exploded view of their connection is shown in Fig. 231. The construction of this device is such that power is transmitted from the starting motor to the engine through the planetary gears when a brake band controlled by a lever on top of the starting holds the gear housing stationary. The complete device is shown in Fig. 232. When the gear housing is free to turn and the engine speeds up the armature of the dynamotor is driven by the overrunning roller clutch. This combination allows the armature to operate at a higher speed in relation to the engine speed when the dynamotor is acting as a motor than it does when the dynamotor is being driven by the engine or when the dynamotor is acting as a generator would operate.

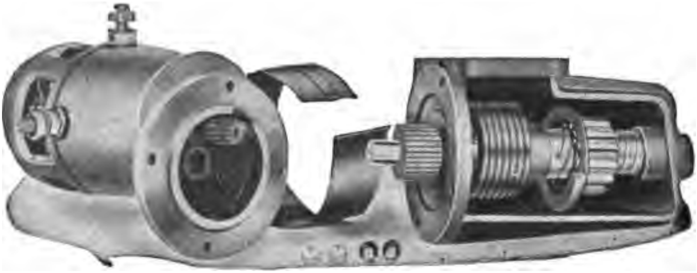


Fig. 229—Gear reduction in which the gearing is supplied by the maker of the electrical equipment

Starting, Lighting and Ignition

The complete electrical equipment of the modern motor car ordinarily includes the three functions, starting, lighting and ignition. To consider the equipment as a whole, all three functions must be taken into consideration, though in a great many installations the ignition function either is quite separate or nearly so from the other two functions.

Relation Between Functions

The equipment by which the starting, lighting and ignition functions are maintained is arranged in different ways, and it is on the arrangements that the first general classification of all systems is based, and the design of the different units depends on which of the arrangements is employed. The electrical equipment which performs the ignition, lighting and starting of the motor car consists of the following main pieces of apparatus:

First, for the ignition there must be a source of electrical energy, either a storage battery, dry battery, the familiar type of magneto generator or a generator which is not of the magneto type. In addition there must be means for transforming the low voltage current into a high voltage or high tension current and other means for distributing the current to the proper spark plug at the proper time.

Second, for lighting there must be a source of energy, such as a storage battery, which may be used in operating the lamps and signalling apparatus, and a generator which is equipped with the proper regulating devices and cutout so as to keep the battery fully charged.

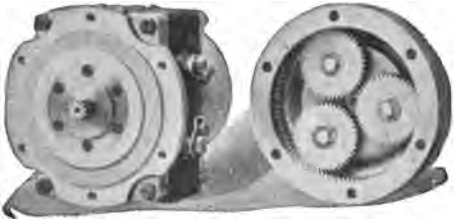


Fig. 230—Gear reduction used on Westinghouse starting motors

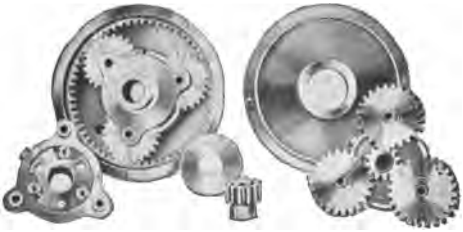


Fig. 231—Exploded view of Wagner gear connecting dynamotor to the engine

Third, for starting the engine there must be an electric motor connected mechanically to the gasoline engine and connected electrically to the storage battery through the proper switches so that the battery will produce an electric current in the windings of the motor, causing its armature to revolve with sufficient force to turn the engine crankshaft over at the desired speed for starting. The battery producing the current to the windings of the motor must, of course, be charged in order that the battery be ready to meet any reasonable demands of the starting motor.

It is evident that the equipment required in performing any one of the above three functions need not be entirely independent of the equipment required in either or both of the other two. For example, the same storage battery and charging generator which supply energy for lighting the car may be used in producing current in the winding of the starting motor and, in many instances, for the ignition. Also, it has been found that other combinations of the equipment required in performing the above three functions may be made for the sake of lightness and simplicity.

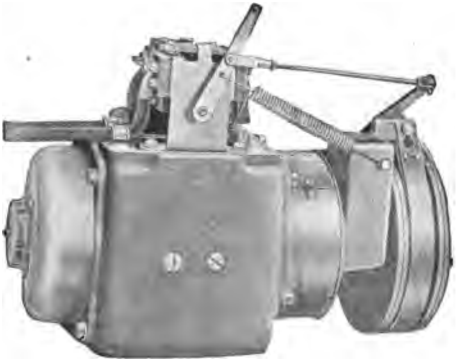


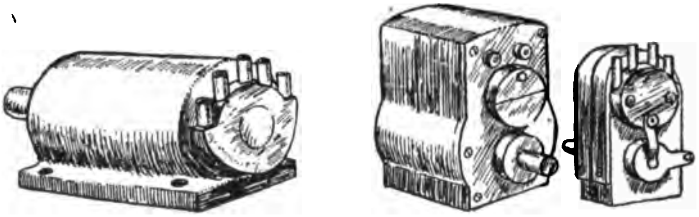
Fig. 232—Complete Wagner dynamotor, an exploded view of whose connection was shown in the preceding figure

There are, however, three fundamental parts to each system, no matter how the equipment required for these various functions may be interrelated, the ignition device, the charging generator and the starting motor. The manner in which these fundamental parts are related affords a means of classifying all starting, lighting and ignition systems into three classes—three-unit systems, two-unit systems and single-unit systems.

Difference in Names

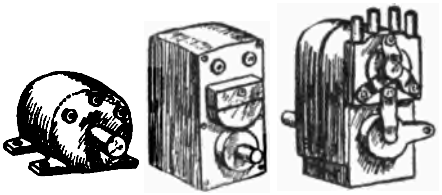
Many manufacturers of these systems disregard the ignition feature in the nomenclature of their apparatus so far as the types of systems are concerned. Thus, they consider only two systems, the single-unit and the two-unit. The former comprises the type in which generator and motor are combined and the latter the type in which the generator and motor are separate. The ignition may or may not be separate and does not affect their nomenclature. Since the ignition is a part of the electrical equipment frequently used in combination with the generator, the division into one-, two- and three-unit types is considered the more logical. The units of the three systems are illustrated in Fig. 233.

Fig. 233—Units of the three systems



Single-unit motor-generator

Two-unit motor with generator and ignition separate



Three-unit, a motor, a generator and ignition

Three-Unit Systems

The three-unit system is one in which the starting motor, the charging generator and the ignition device are separate machines, their only interconnections being to the common storage battery, though in some systems of ignition, where magneto alone is used, the ignition has no connection at all with the other electrical equipment. The component parts of a three-unit system in which the starting motor, generator and magneto are distinct is shown in Fig. 234. The illustration explains how the units receive power from, or deliver power to, the crankshaft of the engine.

Two-Unit Systems

Two-unit systems are those in which any two of the three functions are taken care of by a single machine, leaving the remaining unit to take care of the third function. The generator which supplies current to the battery may be fitted with an induction coil, contact breaker and distributor, so that it performs all of the functions of the ignition magneto and at the same time charges the storage battery. This leaves the cranking to be taken care of by a separate motor. Fig. 235 shows how the charging generator and ignition equipment are combined in a single unit, the starting motor being entirely separate, with the exception of its electrical connection to the same storage battery as the combined generator-ignition unit. Fig. 236 illustrates another design of this combination.

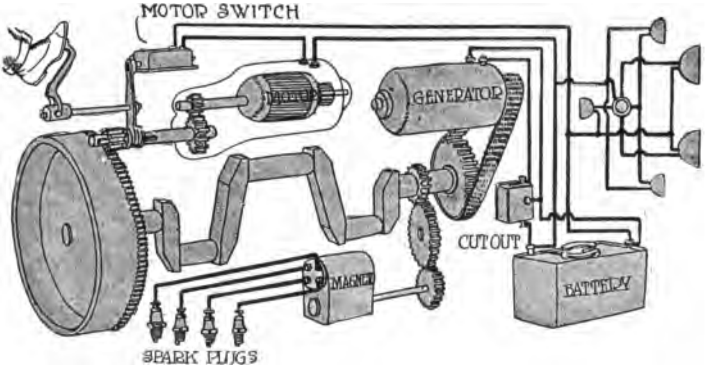


Fig. 234—Typical arrangement three-unit system, showing the mechanical and electrical connections of the separate units, the cranking motor, lighting generator and ignition magneto

In some types of two-unit systems the starting motor and the generator are combined as a single unit, leaving the second unit

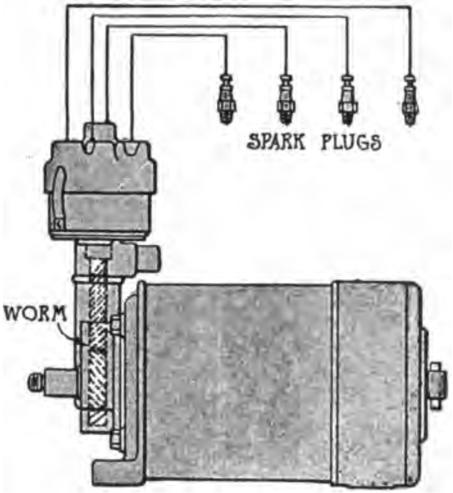


Fig. 235—*One unit of a two-unit system. This is a combined lighting and ignition generator, the cranking apparatus being separate. The distributer is driven by a worm and vertical shaft*

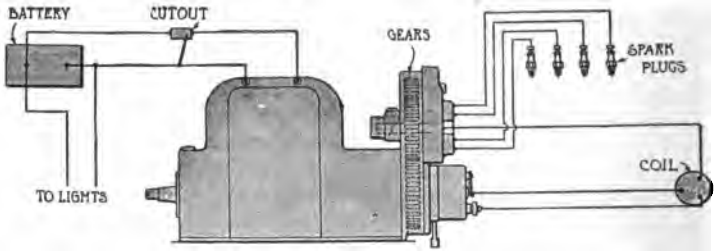


Fig. 236—*A two-unit system similar to Fig.* 235 *except that the distributor is on a horizontal shaft*

to take care of the ignition. The ignition may be taken care of by a magneto, in which case the ignition is entirely independent of the motor and generator functions, or the ignition may be taken care of by an induction coil which draws current from the same storage battery used in combination with the generator and motor.

In two-unit systems the generator and motor are combined in a single unit in a number of different ways. Instead of having two separate machines, they may be combined in the same frame, but each have a distinct field and armature of its own. An example of a combination of motor and generator in the same frame is shown in Fig. 237. In reality this combination is in itself a two-unit system, as the generator and motor actions are entirely independent of each other. The type of construction shown in Fig. 237 is called the double-deck arrangement.

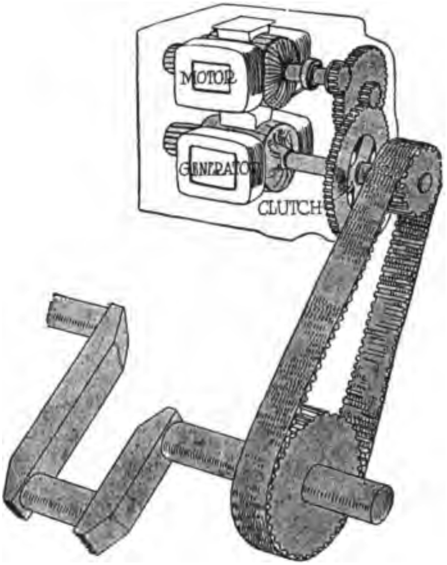


Fig. 237—*Double-deck arrangement of motor and generator in same frame*

Another method of combining the generator and motor actions is to provide two separate windings on the armature of the same machine, one winding being the generator winding and the other the motor winding. This combination of motor and generator in a single machine is called a dynamotor—sometimes, motor-generator. Each of the armature windings is provided with a separate commutator and brushes. A machine of this kind is shown diagrammatically in Fig. 238, both commutators in this particular case being on the same end of the armature. When operating as a motor the machines usually drive through a gear on the flywheel, intermediate gear, or by silent chain to the crankshaft. When operating as a generator, the machine is usually driven by the timing gears or by means of a silent chain.

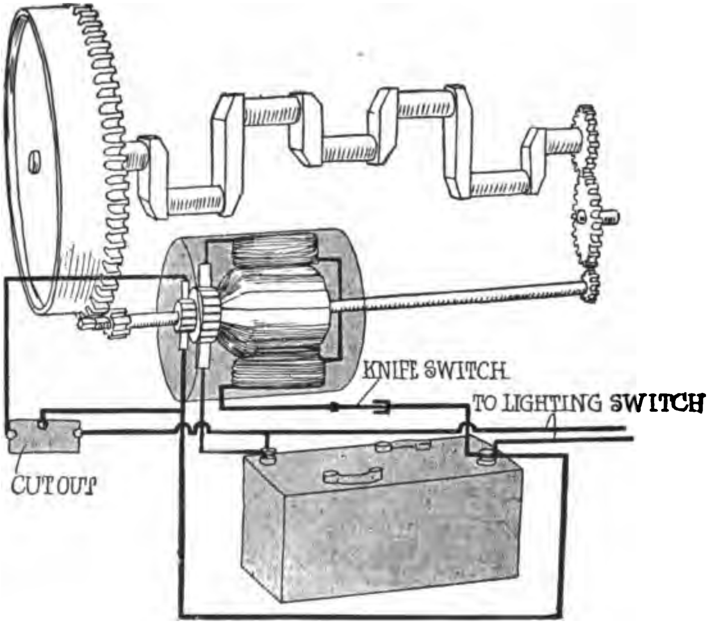


Fig 238—Application of a dynamotor in a two-unit system. It has two separate windings

Single-Unit System

Single-unit, or unit, systems are those in which the starting, lighting and ignition are all taken care of by the same machine.

This consists of a dynamotor which has a contact breaker, induction coil and distributor fitted to its generator end. A complete system of this kind is shown diagrammatically in Fig. 239.

General Classification of Systems

There are three general systems employed for wiring a car,

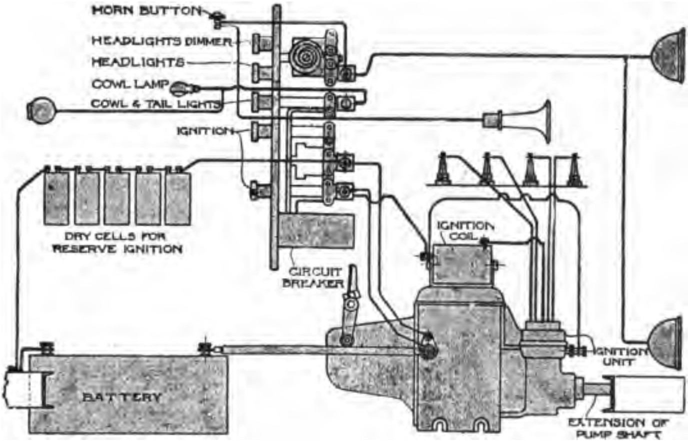


Fig. 239—*Typical single, or one-unit, system*

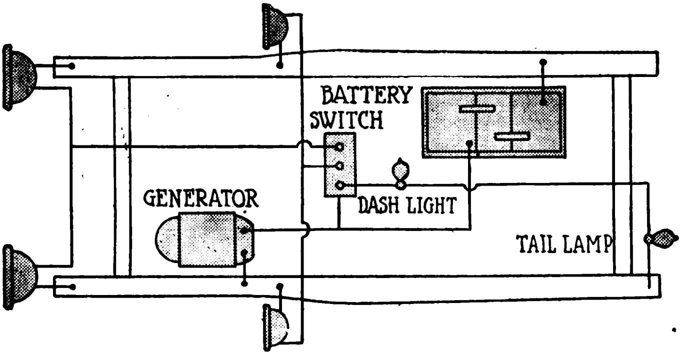


Fig. 240—*Single-wire, or grounded return, system*

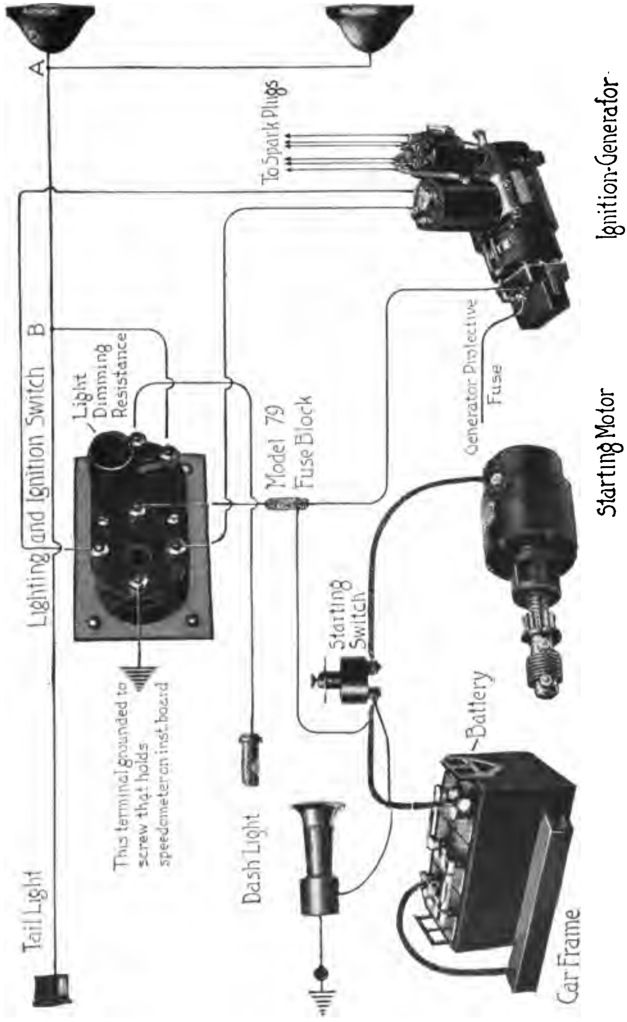


Fig. 241—Remy single wire, or ground return, system as applied to an Oakland 32

as follows: The single wire or grounded return, the two-wire and the three-wire system, respectively.

In the single-wire or grounded-return system the various electrical circuits are completed by using the frame of the car

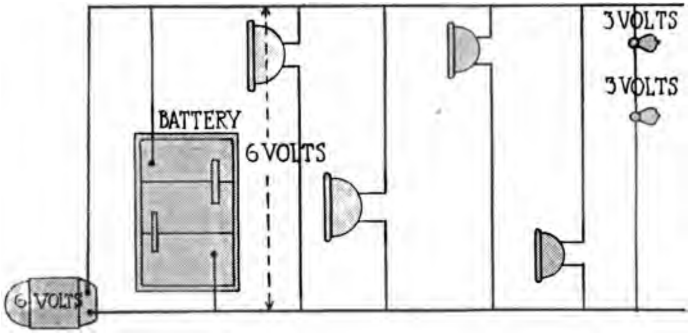


Fig. 242—*Two-wire system. Both sides of the circuit are insulated from the frame of the car*

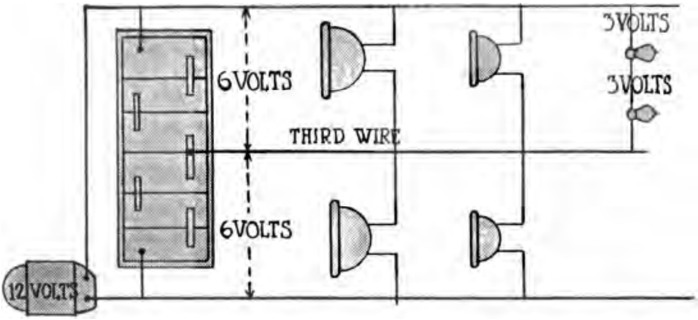


Fig. 243—*Three-wire system, one of which wires is known as the neutral*

as a part of the circuit, as shown diagrammatically in Fig. 240. A pictorial diagram of an actual installation of this kind is shown in Fig. 241. This is a Remy installation on an Oakland Model 32 car. Great care should be exercised in making the electrical connection to the frame of the car to see that it is as perfect as possible and not likely to work loose or be affected by corrosion due to moisture or acid fumes. In some systems the positive terminal of the battery is grounded, while in others it is the negative terminal.

In the two-wire system both sides of the electrical circuit are insulated from the frame of the car and the electrical circuits are completed by wires. Such a system is shown in Fig. 242.

The three-wire system consists of three wires, one known as the neutral and arranged as shown diagrammatically in Fig. 243. The middle, or neutral, wire divides the battery into two parts, and the lamps and other electrical equipment may be connected between either of the outside wires and the neutral or between the outside wires. When the lamps are connected as shown in Fig. 243, if the fuse blows on one side the lamps on the other side still remain lighted. A good example of an installation of this kind is found in certain types of the U. S. L. systems. In these installations the connections of the starting switch are such that the two sections of the battery are in parallel when operating the starting motor and in series the remainder of the time. All the lamps are in parallel and connected to the two batteries in parallel when the starting motor is being operated.

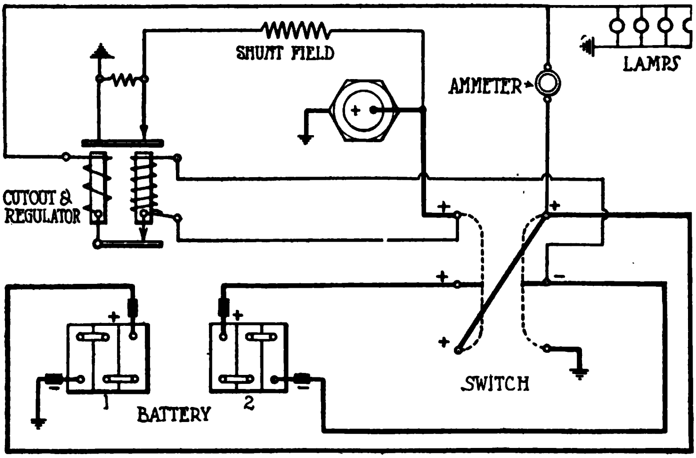


Fig. 244—Simms-Huff system, which is a multiple-voltage system in which the two battery sections are connected in series

Operating Voltage

Starting, lighting and ignition systems may be classified according to the value of the operating voltage into two main groups as follows: Single voltage systems and multiple voltage systems.

Single-Voltage Systems

A single-voltage system, as its name indicates, is a system employing a single voltage for all the electrical operations. The value of this voltage, as used at the present time, is in the great majority of cases either 6 volts or a multiple of 6 volts, such as 12, 18, etc. The selection of the value of 6 as a unit is due to the voltage required in operating the old battery ignition systems, when dry cells were used and the three storage cells seemed to give very satisfactory results when used to replace the dry cells. The advancement made in the last few years in the manufacture of efficient low-voltage charging generators and motors has done a great deal toward making these lower voltages standard rather than the higher values as originally used. The filaments of the lower voltage lamps are more rugged than those of the higher-voltage ones of the same candlepower, which is in favor of the use of the lower-voltage system. The losses in the lower-voltage systems are apt to be quite a bit greater than in the higher-voltage systems, due to the fact that a higher current will be required for a given power unless a larger size wire and larger switch contact areas be employed.

Multiple-Voltage Systems

Multiple voltage systems are those employing more than one voltage. In systems of this kind two voltages are usually employed, one for charging the battery and then a higher voltage for operating the starting motor. In such systems the battery usually is split into two sections. These two sections normally are connected in parallel, and the voltage of the charging generator is such that the battery may be charged while connected in this way. A change in connections usually is made at the starting switch when the starting motor is to be operated, which results in the two sections of the battery being connected in series, and the voltage applied to the starting motor is that of the two sections combined. A good example of a system of this kind is found in the Simms-Huff system, as shown in Fig. 244. The connections are shown diagrammatically in Figs. 245 and 246 for the charging and starting position of the starting switch. In this system the generator and motor actions are combined in a single machine.

In some of the earlier forms of Delco equipment the battery was composed of twelve cells, which were connected in four groups of three cells each. These groups were connected in parallel while charging and in series for operating the starting motor by quite a complicated switch. These switches were mounted on the end of the battery box proper and alongside an ampere-hour meter.

CHAPTER XVIII

Switches and Protective Devices

THE purpose of a switch in any electrical circuit is to provide a means of controlling the operation of the circuit by opening and closing or completing the circuit just as a valve in a hydraulic circuit or pipe affords a means of opening and closing the circuit of which the pipe is a part. Electrical switches assume many different forms and sizes, depending upon the service for which they are designed primarily, which places certain requirements upon the switch in order that it operate successfully. Thus, a switch that is to carry a heavy current must be constructed with large contact surfaces in order that the resistance of these contacts be low; the surfaces of the materials which come into contact with each other must be smooth and should be in actual contact over as large an area as possible; the operation of the switch should be as positive as possible, and all connecting terminals and parts should be of ample size to meet the

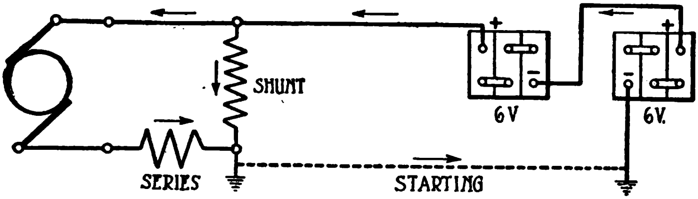


Fig. 245—*The charging position of the starting switch, showing the connections at that position*

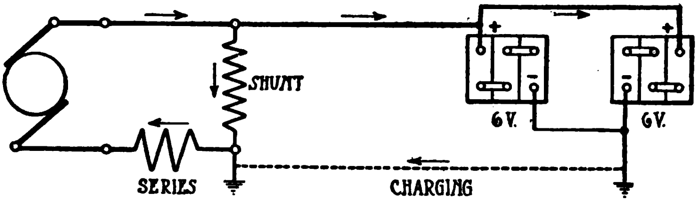


Fig. 246—*The starting position of the starting switch, showing the connections at that position* ordinary requirements to be imposed on the switch when in actual service.

In a great many cases certain parts of the switch are made up of a number of thin pieces of copper instead of one single heavy piece. This construction gives much better contact and also a surer contact in the majority of cases. A switch of this kind is said to be laminated. The selection of the material to be used at the breaking points of the switch will depend upon how severe an arc is likely to form and the probable destruction or damage resulting from such an arc. The breaking contacts are in some cases made of carbon, but in the great majority of cases metal is used. Switches that are to carry a small current, such as those ordinarily found in the lighting circuits of a motor car, are much smaller and require smaller contacts and smaller parts as a whole; but their operation should be quite positive to reduce the tendency for arcs to form at the points of contact when these contacts are being made and broken in the operation of the switch. If a switch is to be used in a high pressure circuit, such as the secondary circuit of an induction or ignition coil, it must be constructed in such a manner and of such materials that it easily will stand the electrical pressure to which it will be subjected under all ordinary working conditions. The construction of any switch is influenced greatly by the location in which it is to be mounted and the manner to be employed in operating the switch.

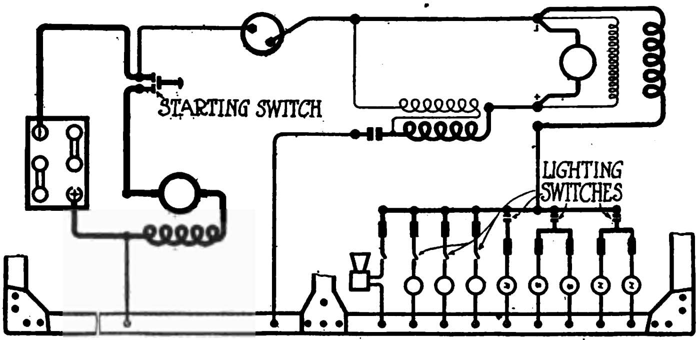


Fig. 247—Wiring diagram of Gray & Davis grounded system, illustrating application of single-pole switches

Quite often a switch is used to change the connection of the various elements of a circuit rather than to serve as a means merely of opening and closing the circuit. A good example of this requirement, as imposed upon a switch, is found in those systems where the connections of the various sections of the battery are changed from a multiple connection while the batteries are being charged to a series connection when the batteries are being used in operating the starting motor. In some cases a switch is introduced into a circuit merely for the purpose of reversing the connections of a certain part of the circuit with reference to some other part. Thus, in certain ignition systems we find what commonly is called a polarity switch, its purpose being to reverse the connections of the interrupter points with respect to the battery or generator in order that the wasting away of the two interrupter points may be equalized. If the direction of the current through an interrupter remains unchanged in direction, there will be quite a difference in the degree to which the two contact points are worn away. The metal naturally tends to travel in the direction of the current, and as a result there is a much greater wasting away of the positive contact than there is of the negative con-

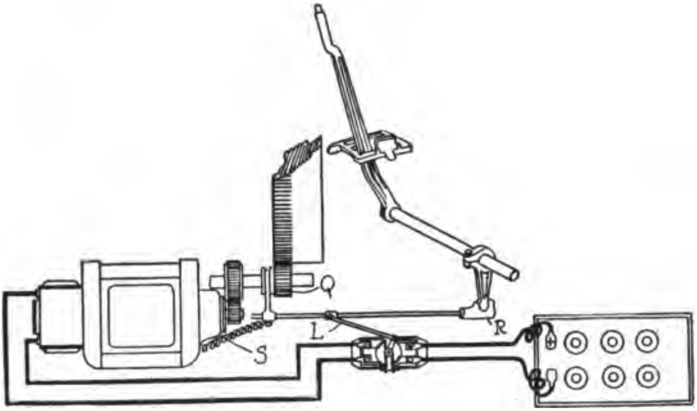


Fig. 248—*Connections of two-pole rotary switch on the* 1913 *Haynes car. The letters are for later reference*

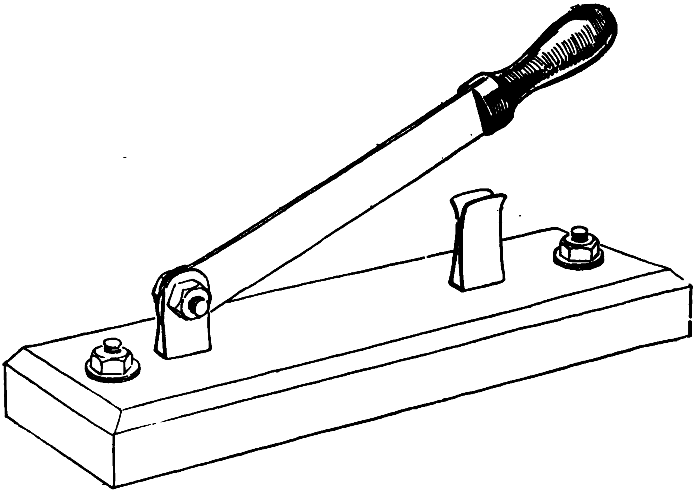


Fig. 249—*Here is a common form of the single-pole blade switch*

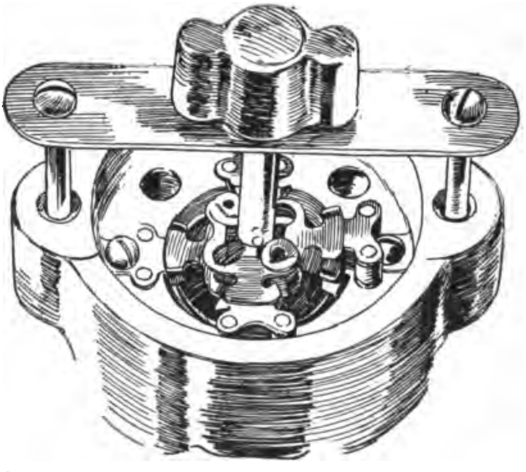


Fig. 250—*Interior mechanism of two-pole snap switch* tact. An inspection of a set of contacts that have been in service for some time will convince you of this fact.

Single and Multipole Switches

A single-pole switch is one in which provision is made for opening the electrical circuit in which the switch is connected at one point only. An example of a switch of this kind is shown diagrammatically in Fig. 247. The positive terminal of the battery is grounded in this case, and the starting motor and its series field winding are connected permanently in series to the positive or grounded terminal of the battery. The starting switch is introduced in the lead connecting the negative terminal of the battery and one terminal of the armature of the starting motor. The lighting switches in this figure are also single-pole, and their connections are very similar to those of the starting switch. Current for the lights flows through the series field of the generator and serves to raise its voltage, which increases its output the required amount to take care of the lamps when they are turned on.

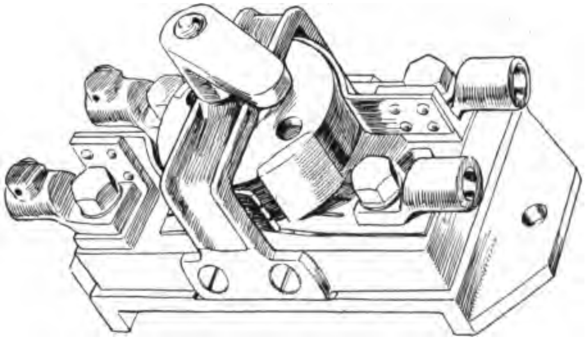


Fig. 251—*The rotating, or drum, switch, used by the Leece-Neville Co.*

A two-pole switch is one provided with two sets of contacts. Two-pole switches may be so connected that one set of contacts is introduced in one circuit and the remaining set in another circuit, which really amounts to two single-pole switches mechanically connected together, and both circuits are operated at the same time. In the great majority of cases, however, the two sets of contacts of a two-pole switch are introduced in the same circuit, one set being introduced in one side of the line and re maining set in the opposite side of the line. A good example of a two-pole switch is shown diagrammatically in Fig. 248, which represents the connections of the rotating starting switch on the 1913 Haynes car.

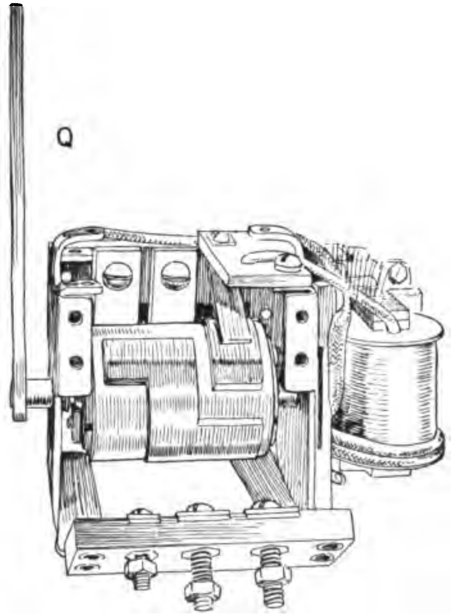


Fig. 252—*The rotating, or drum, switch used by the Wagner Electric Co.*

Multipole switches are those having more than a single set of contacts. A very good example of a multipole switch is found in early models of the Delco systems, in which the switch was used for connecting four sections of a storage battery in parallel for charging and in series for operating the starting motor.

Kinds of Switches

A blade switch is one in which the connection is completed by a metal blade which may be caused to move into contact with the side of a metal jaw or between two metal jaws. A common form of single-pole blade switch is shown in Fig. 249.

A snap switch is one in which the opening and closing of the electrical circuit, or circuits, which the switch is to control is performed by a snap action in the switch. This snap action is produced by a coil spring which winds up as the handle of the switch is turned. After a certain movement of the handle the spring is released and allowed to cause the contacting mechanism of the switch to rotate through a fractional part of a revolution. This rotation of the contacting mechanism is performed in a very short time, thus reducing the tendency for electric arcs to form at the points of make and break. An example of a snap switch is shown in Fig. 250, in which the switch cover is removed partially so that the interior is somewhat exposed to view.

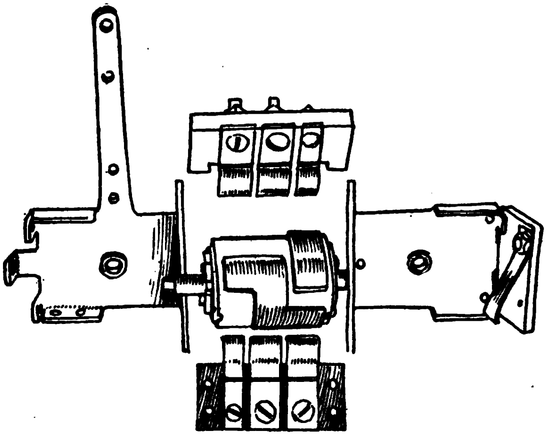


Fig. 253—*Exploded view of drum switch used by Wagner Electric Co.*

A plug switch is one in which the switching action is performed by moving a plunger in or out of an opening in the top of the switch cover. This plunger may be made of metal or insulating

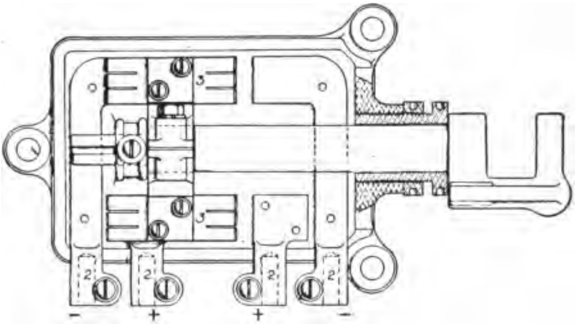


Fig. 254—*Double-pole switch of the sliding type, in which there are two sets of contacts*

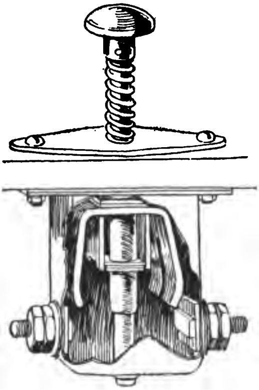


Fig. 255—*Example of thrust type of switch in which an end or thrust movement performs the operation*

material, and if made of metal it may form part of the electrical circuit when the switch is closed, though not always. The plug itself may be so constructed that it can be removed and the switch made inoperative until the plug again is inserted. Plug switches usually are confined to the operation of ignition and lighting circuits.

A rotating, or drum, switch, is one in which the switching operation is accomplished by a rotating member. Two good examples of switches of this kind are shown in Figs. 251 and 252. The switch shown in Fig. 252 is one used by the Leece-Neville Co. in the starting motor circuit shown diagrammatically in Fig. 249. The switch shown in Fig 252 is made by the Wagner Electric Mfg. Co. An exploded view of this switch is shown in Fig 253.

The switching operation in the case of a sliding switch is accomplished by moving a set of contacts so they complete a circuit between fixed contacts. A double-pole switch of this kind is shown in Fig. 254, in which the figures 3 represent the movable contacts and the figures 2 represent the stationary contacts. The switch is in the open position as shown in the figure, and the movable contacts are controlled by the shifting rod 1.

In certain types of switches, which might be called thrust switches, the switching operation is performed by an end or thrust movement of some part of the switch. A good example of a switch of this particular type is shown in Fig. 255, and its operation is quite simple. The switch normally is held open by the coiled spring, but when sufficient pressure is brought to bear on the button or pedal, the contacts may be brought into contact with each other and will remain in contact until the pressure on the pedal is removed. The action of the spring then will open the switch.

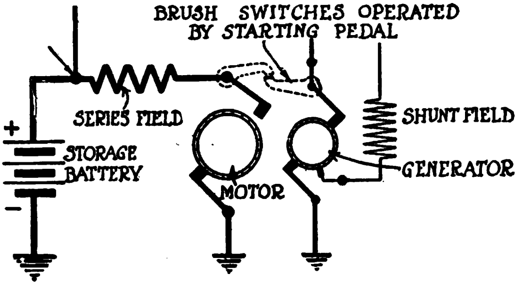


Fig. 256—Diagram of brush switch used in the Delco systems

A brush switch is one in which the switching operation is performed by raising and lowering one of the brushes on the machine. A starting switch of this kind, as used on the Delco systems, is shown in Fig 256. Depressing the starting pedal lowers the motor brush and at the same time makes the generator end of the machine inoperative by raising one of the generator brushes.

A grounded switch is one in which no attempt is made to keep both terminals of the switch insulated from the frame of the car, and in fact one terminal is connected purposely to the switch housing or car frame. A switch of this kind is shown in Fig. 257.

An insulated switch is one in which both terminals of the switch are insulated from the switch housing. A switch of this kind is shown in Fig. 258.

Control and Location of Switches

Switches may be classified conveniently according to the means employed in operating them into the following groups:

Manually operated.

Electrically operated.

Combined manually and electrically operated.

In the case of the manually-operated switch the opening or closing of the switch, or perhaps both operations, are performed by the movement of a lever, pressing a button, pulling or rotating a handle, etc., which is usually within easy reach of the driver of the car. The switch itself may be mounted directly with the controlling handle, button or knob, or it may be mounted in some more advantageous positions so far as the electrical circuit, of which it is a part, is concerned and the operating movement transmitted to it by suitable mechanical connections such as rods, chains and levers. It is especially desirable to locate the starting switch for the motor in such a position that the connecting leads to and from the switch will be as short as possible, and still have the switch within easy reach of the driver when he is in the driver's seat.

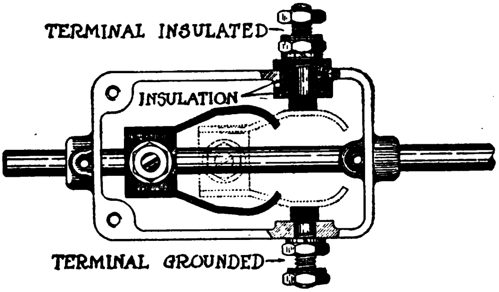


Fig. 257—Grounded switch. One terminal is connected to the switch housing

A manually-operated switch which is operated by a rod is shown in Fig. 249. The gear-shifting lever in this case is used in imparting the necessary motion to the rod controlling the switch. An extra position is provided for the gear-shifting lever, and when in this position all the gears are out of mesh and the lever is connected to the rod R, which is connected by the second rod or link L to the lever of the switch. The rod R serves the double purpose of operating the switch and meshing the motor pinion G with the teeth on the edge of the flywheel. When the pressure is removed from the gear-shifting lever it will be restored to its neutral position, due to the action of the spring S. The motor-starting switch, shown in Fig. 259, is intended to be mounted directly under the floor board in front, or within easy reach of the driver, and the button is mounted on the upper end of a rod which extends through a hole in the floor board.

In the case of an electrically-operated switch, the movements of the switch are controlled by electromagnets, which may be energized by closing a small switch within easy reach of the driver. This small switch completes the circuit from the storage battery through the winding of the electromagnet. The principle of a switch of this kind is shown in Fig. 260. Closing the push button switch completes the circuit from the grounded side of the battery, which in this case is the positive terminal, through the winding of the electromagnet in the starting switch and finally back to the negative terminal of the battery.

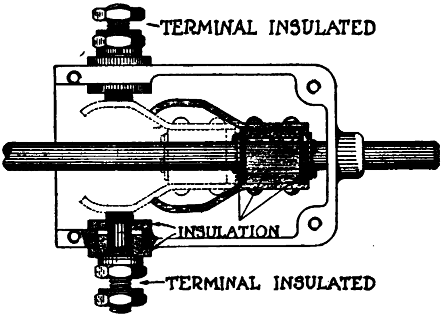


Fig. 258—*Insulated switch. Both terminals are insulated from the switch housing*

In some cases the manual and electrical means of control are combined. A very good example of a switch of this kind is found on the Overland car. In this particular case the manual operation of the starting switch cannot be performed unless a certain electrical operation has been performed previously, which serves to release the switch and permit the manual operation.

Fuses and Circuit Breaker

The primary object of a fuse is to provide a weak spot in an electrical circuit, which will be destroyed when the current the circuit is intended to carry becomes abnormal and thus open the circuit, and perhaps prevent serious damage to valuable equipment. The ordinary link fuse consists of a piece of wire made from metal having a relatively low melting temperature. This piece of wire is connected in series with the circuit, usually by placing its two ends under the heads of two flat-headed screws. These screws form the terminals of the gap in the electrical circuit in which the fuse is to be introduced. A typical fuse block for link fuses, as used by the Remy company, is shown in Fig. 261.

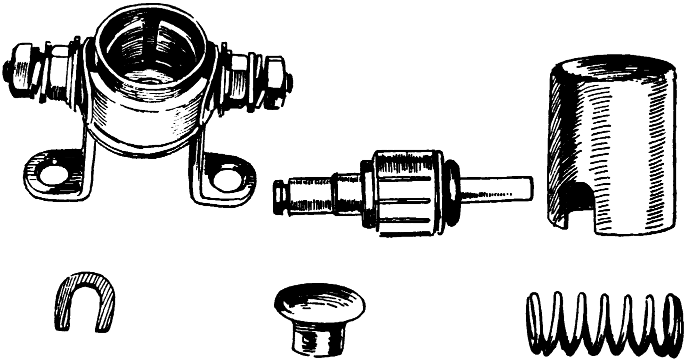


Fig. 259—*Starting switch to be mounted directly under the floor board in front*

In the inclosed type of fuse the fuse wire is incased in a glass or fiber tube, and this tube is provided with metal ends, as shown in Fig. 262. Special clips are provided for accommodating fuses of this kind, as in Fig. 263, which shows several of them mounted side by side.

The circuit breaker is a protective device which serves to open the electrical circuit in which it is connected without destroying any part of the device itself, thus not necessitating any replacements. The operation of a circuit breaker, as used by the Delco company, may be explained by reference to Fig. 264. The circuit breaker winding produces a magnetic pull on an armature when carrying a current, which controls a set of contacts in the main circuit. If the current in the winding of the circuit breaker becomes excessive, due to any cause, such as a ground or short circuit, the armature will be drawn toward the core of the electro-magnet and the contacts broken, which results in the circuit being opened. As soon, however,

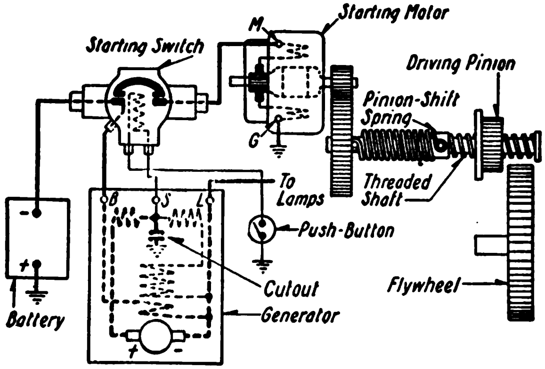


Fig. 260—Diagrammatic drawing of electrically-operated switch

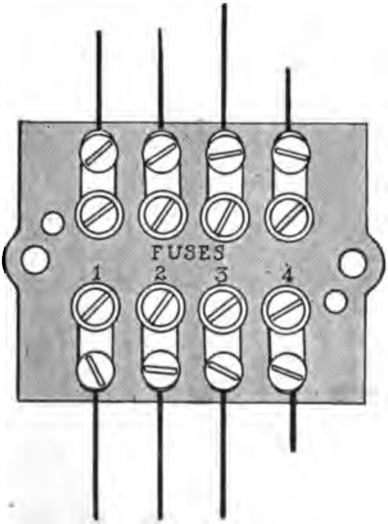


Fig. 261—Fuse block for link fuses as used by the Remy company

as the circuit is opened the magnetic action on the armature ceases and it returns to its original position, thus closing the circuit again. This cycle of operations is performed quite rapidly and results in a sound quite similar to that of an ordinary buzzer. Such a sound is an indication that something is wrong with the system, and an investigation should be made.

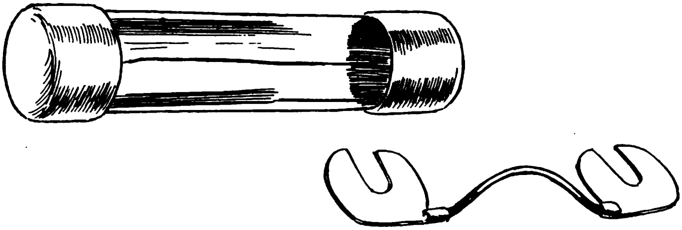


Fig. 262—Inclosed type of fuse wire, incased in glass, left, and link fuse, right

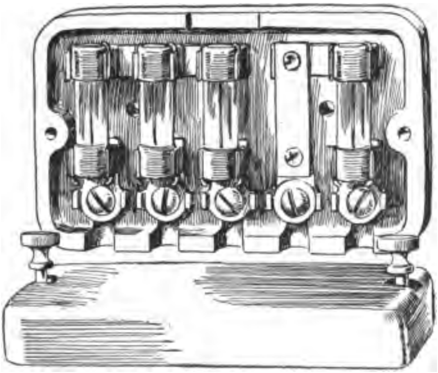


Fig. 263—Special clips for accommodating inclosed type of fuse

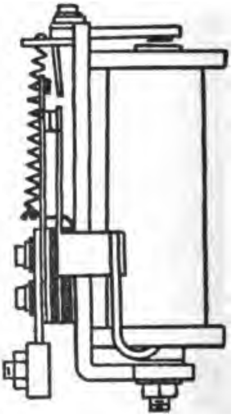


Fig. 264 — Circuit breaker as used by the Delco company

CHAPTER XIX

Electric Lamps

Lamp Filaments

TWO kinds of material are used in the construction of the filaments for motor car lights, tungsten and carbon, and these filaments are placed in two different kinds of bulbs or globes, one in which the exhausted air is not replaced, and the other in which the exhausted air is replaced with nitrogen gas. The first kind of bulb is called the vacuum bulb, and the second is called a nitrogen bulb.

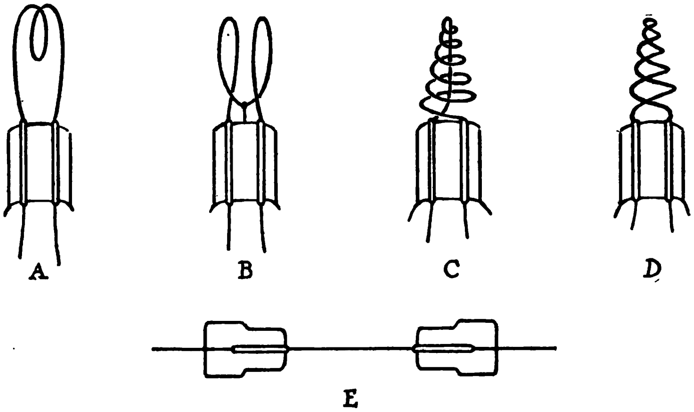


Fig. 265—*Different forms of filaments of electric light bulbs*

Tungsten filaments should be used exclusively because of their greater efficiency, as compared with the carbon filament. The extreme tensile strength of the tungsten wire filaments, which is several times that of steel, enables these filaments to withstand without serious injury all the ordinary jar and vibration encountered in service.

The filaments are formed into several quite different shapes, as shown in Fig. 265. The filament shown at A is not suitable for motor car lights, as it is not sufficiently well supported to withstand the extreme amount of vibration to which it would be subjected. The filament shown at B is called the loop back type and is used in lamps that have non-focusing reflectors, such as side and tail lights. The loop is anchored in the middle, which tends to prevent vibration and hence breaking. The filaments shown at C and D are used where high candlepower is required and exact focusing of the lamp in the reflector is desired. The filament shown at E is just a straight piece of tungsten wire which is connected to two terminals mounted in the ends of a glass tube. Several complete lamps are shown at A, B and C in Fig. 266.

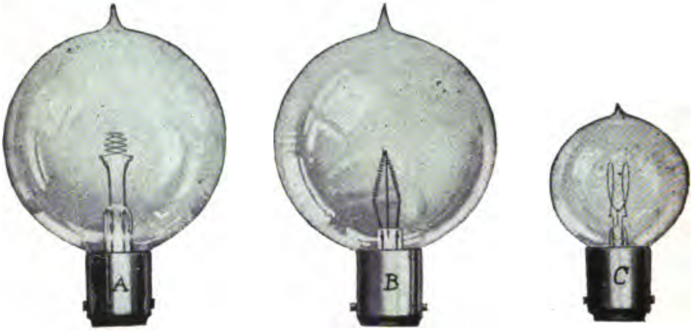


Fig. 266—Examples of filament construction in electric light bulbs

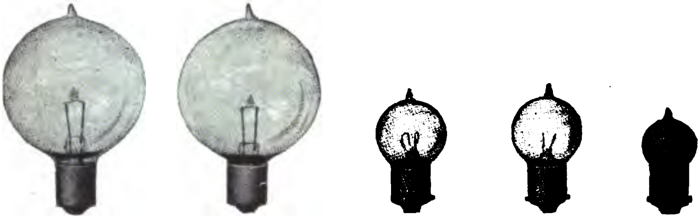


Fig. 267—Typical headlights, side lights and tail light as made by Westinghouse

Classification of Lamps by Base

There are four main types of bulb bases, omitting some special types such as those used by the Bosch company, for example. Two of these four main types are of the familiar screw type and are seldom used except in interior body work, while the other two, called the bayonet type, are in quite common use for all purposes. The Edison type base is often called the Ediswan and makes use of a spring-locking device that holds the bulb firmly in place against jarring and consequent loosening. The base for this type is cylindrical and carries two small projecting pins on the side and directly opposite each other. The socket into which the base fits is also cylindrical and of such dimensions as to make a rather loose fit. Two slots are cut along the sides of the socket, and when the bulb base is placed in position, the projecting pins slide into these slots. At the bottom the slots end in a small upturned notch so that the pins in the base will fit into the notches when the bulb is given a part of a turn. In the bottom of the socket are pins that press against the inner end of the base and keep the pins in place in the notches.

One kind of bayonet base is provided with a single electrical contact in the center of the bottom of the base, this contact coming against a spring, or plunger, in the socket when the bulb is in place. The electrical circuit is completed through this contact on one side, while the other side is completed through the metal of the outside cylindrical portion of the base, where it comes in contact with the metal shell of the socket. This type of base is called the single-contact type and was designed primarily for use with the one-wire, or grounded, system of wiring, in which the shell of the socket is attached to the frame of the car and forms part of the electrical circuit through each lamp. A set of single-contact lamps is shown in Fig. 267.

Another kind of bayonet base has two contact points on the bottom of the base, both being insulated from the metal shell and each other. The circuit is completed through these two contacts, and there are two springs, or plungers, in the socket that make connection with the contacts in the base when the lamp is in place. This is called the double-contact type of base and is used with the two-wire, or insulated return, method of wiring, in which both sides of the circuit are insulated from the frame or metal of the car.

One form of the screw type of base is called the candelabra base, and the other one, which is of smaller form, is called the miniature base. Their construction is similar to those used on lamps for house lighting, except they are both smaller. A single contact carried in the center of the bottom of the base makes contact with a spring in the center of the bottom of the shell. The other side of the circuit is completed through the shell of the base and a thin shell inside the socket, threads being formed in these two parts so that the lamp will screw into the socket.

The filaments of all the lamps are so designed as to length and diameter that they will take a practically definite current from a certain voltage source of electrical energy. If the lamps be operated at a lower voltage than that for which they are designed, there will not be sufficient current sent through them to heat the filament to the required degree, and as a result the lamp will not burn up to its rated candlepower. On the other hand, if they be operated on a lighter voltage circuit than they are designed for, all excessive current will be sent through the filament, which will result in a lighter degree of heat than the lamp is expected to take care of, and as a result there will be a reduction in the useful life of the lamp, and if the voltage be sufficiently high the lamp may be burnt out almost instantly. The voltage ratings, of course, correspond to the voltages of the circuits on which the lamps are to be operated. The voltage of the circuits in motor car work usually is taken as a sixth more than twice the number of cells in the battery. Thus, a circuit connected to three cells would require 7-volt lamps, one connected to six cells would require 14-volt lamps, etc.

The size of the filament depends upon the current the lamp is to carry, and the length of the filament depends upon the voltage the lamp is to work on. Thus, if the current rating of two lamps is the same, and they are designed for six and twelve coils, respectively, then the filament in the 12-volt lamp will be twice as long as the filament in the 6-volt lamp, etc. If the current ratings were in the same ratio as the voltage ratings, then the filament of the 12-volt lamp would be approximately twice the area and twice as long as the filament of the 6-volt lamp.

The watts required for any lamp are equal to the product of its current in amperes and its voltage in volts. The tungsten filament lamps, depending on the candlepower, require from .95 to 1.25

watts per candlepower, while the carbon filament will require approximately 2.5 watts per candlepower. The following is a list of the lights as used by one of the leading companies:

Lights	Candlepower	Amperes of Each
Headlights	15	2.5
Side lights	4 or 6	.84 to 1.25
Tail light	2	.42
Speedometer light (when used)	2	.42
Meter light (when used)	2	.42
Dome light (when used)	2 or 4	.42 or .84
Pillar lights (when used)	4	.83

All the above are 7-volt lamps.

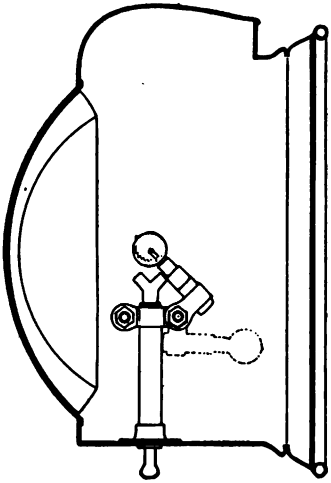


Fig. 268—*Lens-mirror type of reflector*

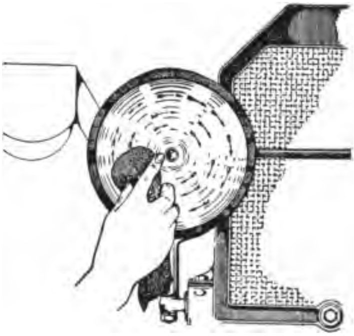


Fig. 269—*Method of cleaning old reflector*

Lamp Reflectors

In brief the object of a reflector is to provide a means of collecting the rays of light that emanate from the source of light in certain directions and re-direct them in such a manner that the light given out by the source of light is confined to a comparatively small part of the space surrounding the space of light.

The earlier forms of reflectors were in the majority of cases of such a shape that they did not intercept a very large portion of the light rays from the source of light and for this reason were quite inefficient. The construction of what is called the lens-mirror type of reflector is shown in Fig. 268. This shows a lamp which originally was constructed to use a gas burner but is now provided with a special electric light attachment which may be moved in or out of position as conditions may demand. In this particular case only the rays of light in a small zone back of the bulb are intercepted by the reflector and re-directed toward the front of the lamp. The reflectors shown in Fig. 271 are of what is called the parabolic type. The advantage of this type of reflector is that it intercepts a very large proportion of the rays of light and for this reason is much more efficient than the lens-mirror type.

The proper device of a reflector for a certain lamp depends almost entirely upon the use that is to be made of the lamp. Thus in side and tail lamps for example a much less efficient type of reflector may be used than in head and spot lights.

Care of Lamp Reflectors

When the lamp reflectors become dirty or tarnished they may be cleaned and brightened, although the surface of the reflector will be somewhat damaged every time it is touched, no matter how carefully the work is done. Ordinary dust and small particles of foreign matter may be removed by blowing it off, and if it does not yield to this treatment, a stream of clean cold water at a very low pressure may be directed against the surface of the reflector. When water is used the reflector should be allowed to dry and then wiped off carefully with a very soft piece of chamois skin. Alcohol may be, and if obtainable should always be, used in cleaning the silvered surface of a reflector. The alcohol may be applied by means of a piece of clean soft chamois skin which has been moistened, the reflector being wiped over with a rotary motion starting at the bulb opening and gradually working out toward the outer edge of the reflector as shown in Fig. 269. The chamois skin should be held against the reflector with a light, even pressure.

After the reflector is tarnished quite a bit it may be polished by moistening the chamois with alcohol and then applying a small quantity of jeweler's rouge. After the tarnished surface has been brightened, the polish may be put on by using a small quantity of the same kind of rouge on a piece of dry chamois skin. The rotary motion should be used in this case just as previously described.

Focusing Lamps

It is necessary that a lamp be in focus in order that the best results may be obtained from the lamp. There is a certain position in a parabolic reflector which corresponds to the focus point, and if a concentrated filament incandescent lamp be mounted in the lamp in such a manner that the source of light in the filament corresponds in position with the focus point of the reflector then the light thrown ahead of the lamp will be along the lines A, A, in Fig. 270. If the lamp is too far back in the reflector the light rays follow the lines B, B, and if the lamp is too far ahead in the reflector the light rays follow the lines C, C. In addition to the lamps being in proper focus their adjustment on the supporting

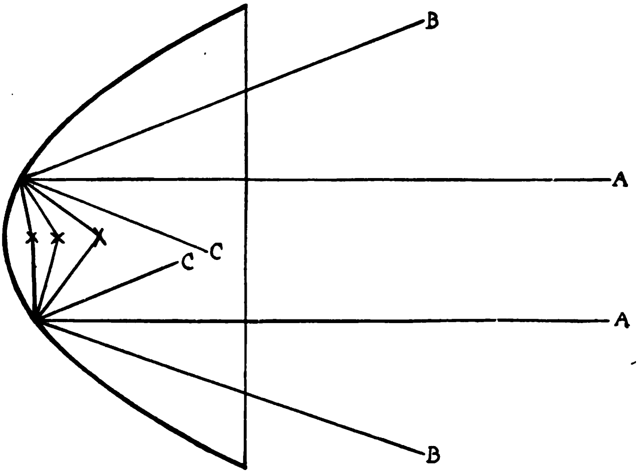


Fig. 270—Direction of light rays for different positions of lamp in a parabolic reflector

brackets must be such that the light is thrown at the proper point on the road ahead.

The bulbs may be adjusted by moving them back and forth in the reflector until the filament is in the proper relation to the curved surface of the reflector. Quite a number of lamps are made so that the bulb position may be changed by turning a small screwhead or nut mounted in the front or back of the lamp housing and exposed so that it is reasonably accessible. Two different types of adjustments are shown in Fig. 271.

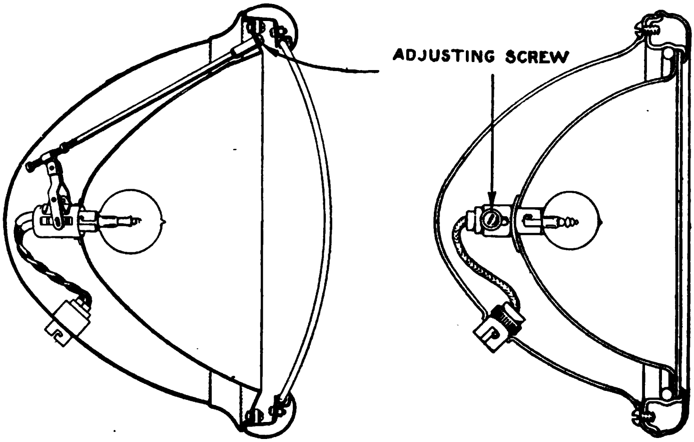


Fig. 271—Reflectors of the parabolic type. This type is more efficient than the lens-mirror type

In focusing the headlights one lamp should be adjusted at a time. The bulb of one lamp should be removed or the lamp covered up in order that the light from it will not interfere with the adjustment of the other one. The focusing, of course, should be done in a rather dark location in order that the best results may be obtained. When the adjustment is made on a road the lamp bulb should be moved back and forth until the light on the road is clean and as free from black spots as possible. If the lamp bulb is adjusted in a garage the light should be directed against a wall and the bulb moved until a clean and clear spot of light appears on the wall.

After the lamps have been focused they should be moved on their brackets so that the spot of light will be directed to the proper point on the road and the desired distance ahead of the car. In some cases it may be necessary to bend the brackets in order to make the last mentioned adjustment.

Wiring and Light Switches

There are three general methods of wiring and connecting the lamps on a car, as follows:

Single-wire system.
Two-wire system.
Three-wire system.

These three different systems of wiring have been described in one of the previous chapters.

The switches used in controlling the light very often are quite complicated in appearance and construction in order that the desired results may be accomplished. A front and rear view of a typical lighting switch is shown in Fig. 272. There are four different positions for the switch as shown in the front view.

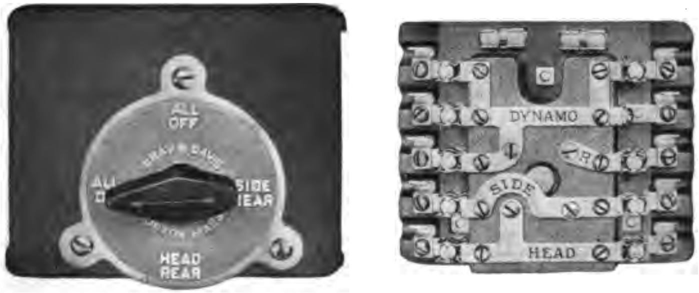


Fig. 272—*Gray & Davis junction switch for controlling the lights in a single-wire, or grounded, system*

Dimming Headlights

One of the simplest devices used in dimming the headlights consists of nothing more than a resistance which may be con-

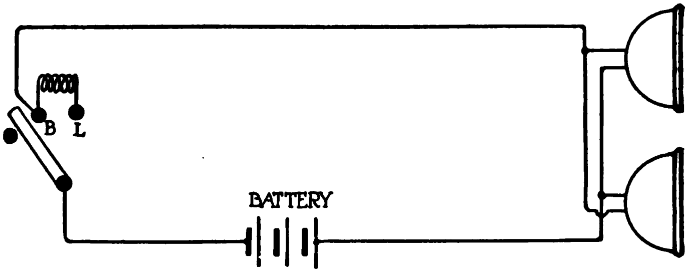


Fig. 273—*Resistance connected in a series with lamps to dim headlights*

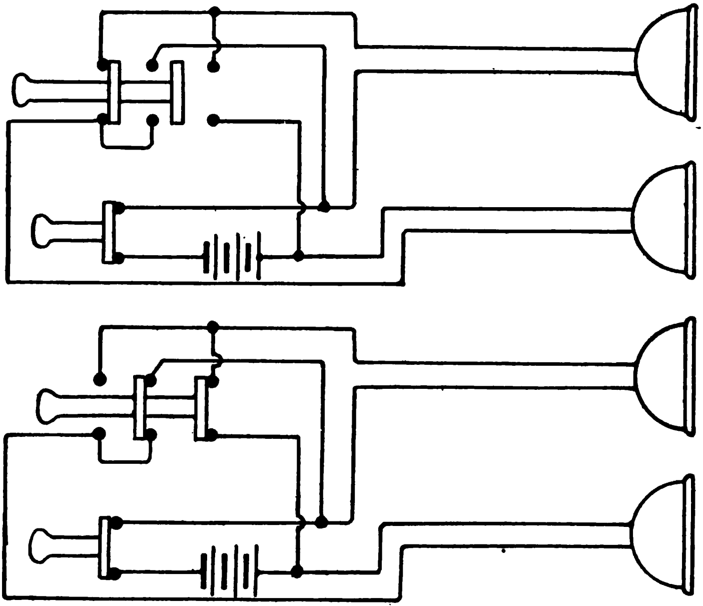


Fig. 274—*Lamps connected in series, above, for a dim light and in parallel, below, for full candlepower*

nected in series with the lamps by means of a switch, mounted in easy reach of the driver. This arrangement reduces the voltage over the lamps which causes them to burn at a much lower candlepower than their rated value. The connections of a dimmer of this type are shown diagrammatically in Fig. 273. When the switch is on the point marked O the circuit is open; when it is on the point B the lamps burn at full voltage; and when it is on the point L the lamps burn at a voltage lower than their rated value.

In some cases the lamps and switch are so connected that the lamps may be connected in series for a dim light and in parallel for full candlepower. A diagram of a system of this kind is shown in Fig. 274.

The high candlepower electric lamps are the cause of a great deal of trouble due to the blinding glare they produce, and as a result the driver of a car is greatly annoyed when he is compelled to drive toward high-powered headlights. A great deal has been done by various motor organizations and there has been some legislation to bring about a more reasonable use of high candlepower lamps.

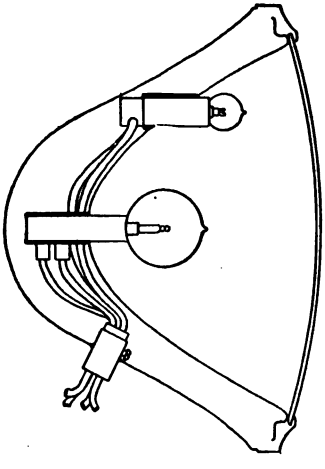


Fig. 275—*Double headlamp*

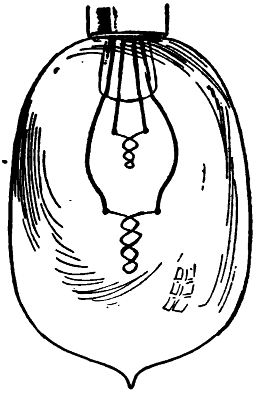


Fig. 276—*Double filament*

Two bulbs quite often are used in each headlight, as shown in Fig. 275. The second bulb is of low candlepower, and in addition it is out of focus. As it is inserted in the upper side of the reflector, most of the light is directed downward, all of which results in practically no glare. A very similar result is obtained by the use of two filaments in a single bulb as shown in Fig. 276. The back filament is employed for the high candlepower light and is in focus while the outer filament is for the low candlepower light and is out of focus.

CHAPTER XX

Electrical Instruments

THE following electrical instruments are ones that commonly are encountered in motor car work, and their purpose and operation will be described in the following paragraphs: Ammeters, voltmeters, ampere-hour meters, wattmeters, watthour meters.

The ammeter is an instrument to indicate the value of the current of electricity in the circuit of which the ammeter itself is a part.

The voltmeter is an instrument whose construction is such that it will give an indication of the value of the difference in electrical pressure between two points in an electrical circuit to which the terminals of the instrument are connected.

An ampere-hour meter is an instrument for measuring the quantity of electricity passing through an electrical circuit in a given time, and its construction is such that it sums up the successive products of current and time and thus total quantity is registered on a dial by means of a pointer which moves over a graduated scale.

The wattmeter is an instrument for measuring power, that is, current in amperes times electrical pressure in volts. Its construction is a combination of an ammeter and a voltmeter, the product being indicated by a pointer which moves over a graduated scale.

The watthour meter is an energy meter, and it sums up the products of the power and time and registers this product on a dial or dials located on the front of the instrument.

The operation of all ammeters depends upon some effect produced by the electric current. They may be classified conveniently according to the particular effect of the current upon which their operation depends. The two most common effects of an electric current are its magnetic effect and its heating effect, and the majority of the ammeters on the market at the present time depend upon one or the other of these two effects for their operation, especially the magnetic effect. The chemical effect of a current may be used in measuring the value of the current, but this method is so little used in comparison to the magnetic and heating effects that we will confine our description to the two most commonly used effects.

There is a magnetic field surrounding an electrical conductor in which there is a current of electricity, as explained in detail in one of the previous chapters, and the strength of the magnetic field varies with the value of the current in the conductor, increasing with an increase of current and decreasing with a decrease of current. The majority of the ammeters in use at the present time depend for their operation upon this magnetic effect of the current, and their chief difference lies in the method of applying the effect to the operation of the different makes and models.

A very simple form of ammeter is shown diagrammatically in Fig. 277. M is a strong permanent magnet with its ends mounted inside the coil C through whose turns the current to be measured passes, connection to the coil C being made by means of the terminals T 1 and T 2. A small piece of soft wire, I, is mounted on a vertical shaft, P, which also carried a pointer, P 1, with a balance weight, W. The balance weight provides a means of making the instrument read the same in any position. The magnetic action of the magnet M on the piece of soft wire is such that the piece is held in the position shown in the figure when there is no current in the coil, that is, it is held in a position corresponding to the direction of the magnetic field from the north to the south magnetic poles of the permanent magnet.

The direction of the magnetic field due to the permanent magnet is from left to right. If a current of electricity be sent through the coil C, a magnetic field will be produced around the coil, and the direction of the magnetic field inside or outside the coil may be determined by the following simple rule. When you look along a conductor in which there is a direct current, in the direction of the current, the magnetic current surrounding this conductor due to the current in the conductor will be clockwise in direction. Let us assume that the direction of the current is toward the paper in the wires shown in the left-hand cross section of the coil. With the current in the coil in this assumed direction, there will be a magnetic field about the left-hand cross section in a clockwise direction, or down through the center of the coil, and at the same time there will be a magnetic field about the right-hand cross section in a counter-clockwise direction which also will be down through the center of the coil. This magnetic field which the current in the coil tends to produce cannot exist alone but combines with the magnetic field of the permanent magnet and forms a resultant magnetic field. These two magnetic fields may be thought of as two forces whose directions and values are shown diagrammatically in the small figure to the right.

The line marked Fm represents the magnetic field due to the magnet and its direction is toward the right as shown by the arrowhead. The line marked Fc represents the magnetic field due to the current and its direction is down and at right angles to Fm. The lengths of the two lines represent the values of the fields to some convenient scale. The line R represents the resultant field, due to Fm and Fc, both in direction and in value to the same scale as Fm and Fc. The piece of iron, I, will move so that it is parallel to the direction of the resultant magnetic field, which results in the pointer P 1 being moved toward the right over the graduated scale at the top of the instrument. The amount of the deflection of the pointer P from the zero position will depend upon the position of the resultant field R in relation to the field Fm, due to the magnet. The angle between R and Fm, of course, will depend upon the value of Fc, which in turn depends upon the size of the coil, the number of turns in the coil and the current in the coil. Now by properly adjusting the size of the coil and the number of turns, the value of Fc may be made such that when it is combined with Fm to form R, the angle between Fm and R will be of the desired value. For example, the construction may be such that 5 amp. in the winding of the coil will produce a deflection, or movement, of the pointer P from zero to the extreme right of the scale.

If the number of turns in the coil be reduced to half, then twice the current in amperes will be required to give the same deflection of the pointer as originally was produced. The markings on the scale then would have to be changed to twice their present values. If the number of turns in the coil were increased to five times their present value, then only 1 amp. would be needed to make the pointer move from zero to the extreme end of the scale.

The position of the pointer P for various known currents in the coil may be marked, and after such a marking is made the instrument may be used for measuring electrical currents. The current the instrument can indicate will depend upon the turns in the coil C. This type of instrument sometimes is called the wiring iron type. The direction of the deflection of the pointer from zero in an instrument of this kind will depend upon the direction of the current through the winding in the coil C, so that the current in C always must be in one particular direction if the pointer is to be deflected in a definite direction from the zero mark on the scale. Such an instrument can be used in measuring direct current only.

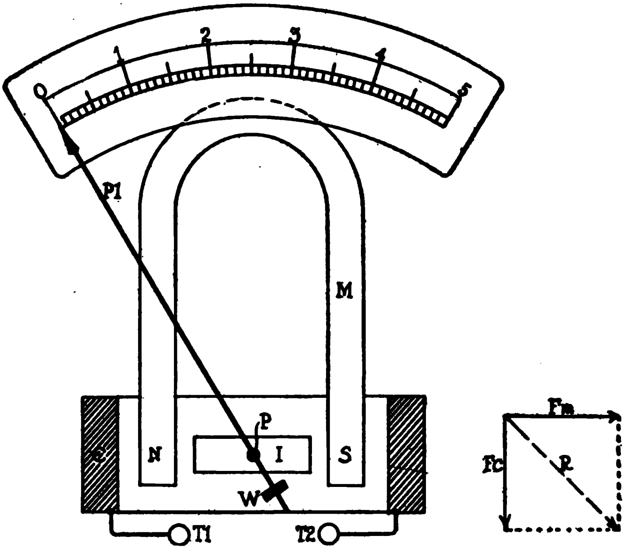


Fig. 277—Simple form of ammeter. This type can be used in measuring direct current only

The instrument shown diagrammatically in Fig. 278 is known as the plunger type. It consists of a curved soft iron plunger, I, mounted on the end of an arm which is carried on the shaft P. A pointer, P, and a balancing weight, W, also are mounted on the shaft P, and the whole system is held in a definite position by the coil spring S. When a current is sent through the coil C it magnetizes the soft iron core C, which then is attracted, or drawn, into the core. The movement of the iron core will depend upon the number of series in the coil C, the strength of the spring S and the current in the coil C. The spring and wires in C may be so adjusted that any desired current will produce a movement of the end of the pointer from one end of the scale to the other. Changing the series in the coil will change the value of the current required for a complete movement of the pointer from one end of the scale to the other, and hence the current capacity of the instrument is changed. The deflection of the pointer in an instrument of this kind is in the same direction regardless of the direction of the current, and such an instrument may be used in measuring an alternate or direct current.

The instrument shown in Fig. 279 consists of a coil of wire, C,

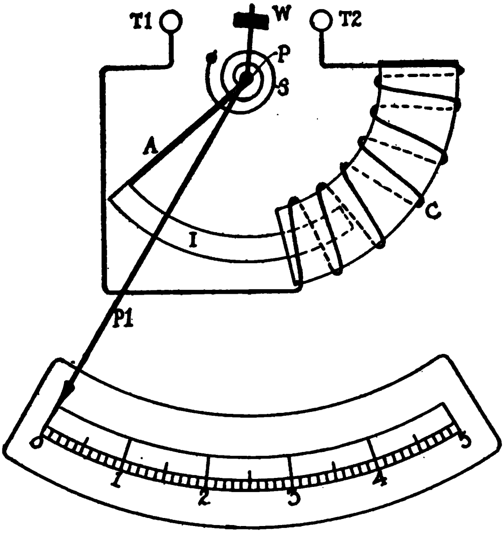


Fig. 278—Plunger type of ammeter. This type can be used for either direct or indirect current

wound on a hollow spool inside of which a piece of soft iron, V 1, called the vane, is mounted on a shaft, P, which is parallel to the axis of the coil but does not correspond in position with the center of the coil as shown in the figure. A second piece of soft iron, V 2, is mounted on the inside edge of the opening of the coil and in about the same relation to V 1 as shown in the figure. The moving parts are balanced by the weight W, and the system is held in its zero position by the spring S when there is no current in the coil. When there is a current in the coil, the two pieces of wire are magnetized alike in polarity, both north poles at the upper end and both south poles at the lower end, or vice versa. The two pieces then will repel each other, which will cause the pointer to move over the scale. The field inside the coil is somewhat stronger near the outer edge, and the piece of iron, V 1, is acted upon by a force tending to draw it into this stronger field, which will be the result as the moving system rotates, due to the shaft P being off the center of the coil. These two forces on the piece of iron V 1 combine to produce a movement of the pointer which will vary in value with the current in the coil and the number of turns. The direction of the deflection of the counter from zero is independent of the direction of the current in the coil, and the instrument may be used in measuring both direct and

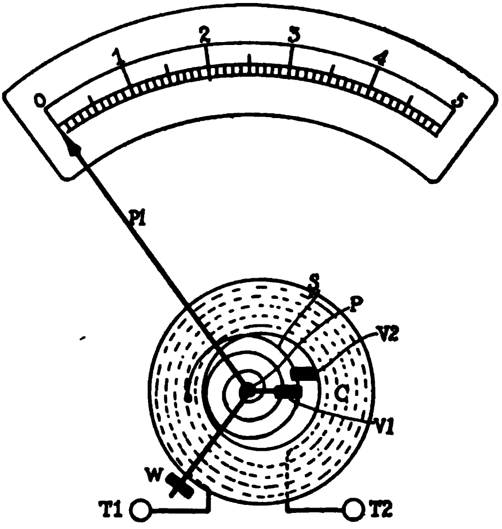


Fig. 279—The magnetic vane type which measures both currents

alternating currents. This kind of an instrument is known as the magnetic vane type.

Most Widely Used

The instrument shown in Fig. 280 is the most widely used of the various instruments operating upon the magnetic effect of an electric current. It consists of a permanent magnet, M, provided with two special hole pieces, P 1 and P 2, between which a cylindrical piece of soft iron, I, is mounted. A coil, C, is wound on a light aluminum frame and pivoted at the top and bottom so that it may rotate about the piece of iron I, the sides of the coil moving in the small gap between I and the pole pieces P 1 and P 2. The current is led into and out of the coil C by two spiral springs, one at the top and one at the bottom, which also serve to keep the coil in its zero position and to provide a restoring force against which a magnetic action of the current in the coil is to act.

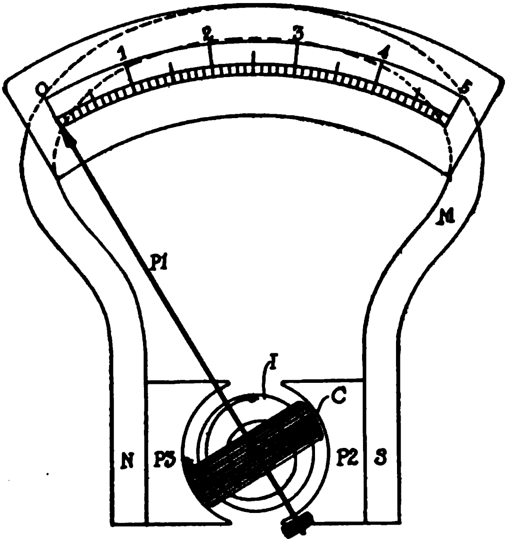


Fig. 280—*The most common type of ammeter*

A pointer, or needle, is attached to the coil and wired over a suitable scale when there is a turn in the coil. In instruments of this kind the wire used in winding the coil is very small and capable of carrying only a very small current. In measuring larger currents than the coil will carry safely use is made of what is called an ammeter shunt, which will be explained in one of the following sections.

When a current of electricity is sent through the coil of the instrument shown in Fig. 280, a magnetic field is produced through the coil, and this magnetic field and the one due to the permanent magnet tend to turn so that they are parallel to each other. Since the coil is free to turn, except for the action of the springs attached to it, there will be a movement of the coil, and the extent of this movement will depend upon the value of the current in the coil. The direction of the deflection of the coil will depend upon the direction of the current in the coil, and hence the instrument can be used only in measuring direct current. A Weston portable ammeter of this type is shown in Fig. 281.

Fig. 281—*Weston portable ammeter*

When a current of electricity is produced in a wire there is a certain amount of electrical work done in causing the electricity to flow against the resistance offered by the wire, just as a certain amount of work is done in causing a current of water in a pipe or overcoming the resistance offered by the pipe to the free flow of the water. In each of the above cases the work done is converted into heat. The amount of heat produced in the case of the water is in the great majority of cases quite small, and for this reason it is not given very serious consideration. The heat generated in the wire, when there is a current in the wire, depends on the resistance offered by the wire and also on the value of the current in the wire.

A good example of the fact that there is heat generated in a wire in which there is a current of electricity is found in all the commercial electrical heating devices and in the incandescent lamp. The heat generated depends on the value of the current, and if it were possible to measure the amount of heat generated in a given time, in a certain wire with a known value of current in the wire, it would be possible to use the same wire in measuring a current by accurately measuring the heat generated and from this computing the value of the current. This method of measuring a current is not commercially possible, and a more practical application of the heating effect is used.

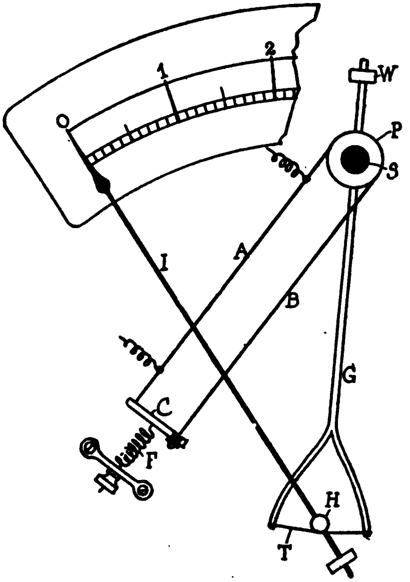


Fig. 282—To illustrate electrical instrument that operates on heating effect of current

The principal of an electrical instrument operating on the heating effect of a current is shown diagrammatically in Fig. 282. A wire, AB, of comparatively high resistance, low temperature coefficient and non-oxidizable metal, has one end attached to the plate C, then passed around a pulley, P, that is secured to a shaft S, and its free end is brought back and mechanically, though not electrically, attached to the plate C. The spring F keeps the wire under tension, it being attached to the plate C, which is so guided that it can move in a direction at right angles to the shaft S. An arm, G, also is attached to the shaft S, being counterweighted at the upper end by the weight W and split open, or bifurcated, at the lower end. A fine silk thread, T, has one end attached to one of the arms at the lower end of G, then passed around a small pulley, H, which is mounted on a shaft that carries a pointer, I, and finally has its other end attached to the second arm of G. The material composing the arms of G is springy and serves to keep the silk fiber in tension.

The current to be measured passes through the wire A, entering and leaving through two twisted conductors, as shown in the figure. When a current is passed through A it is heated and expanded, which usually results in the tension in A being less than that in B. The tensions originally were the same, and equilibrium can be restored only by the pulley P rotating in a clockwise direction. This rotation of the pulley P causes the lower end of the arm G to move toward the left. The silk thread that passes around the pulley H causes it to rotate in a clockwise direction, and as a result the needle, or pointer, I, is deflected toward the right, being rigidly attached to the pulley. Changes in the temperature of the entire instrument affect both the wires A and B alike, and there is, as a result of this equal change in their lengths, no movement of the pointer I. An instrument of this kind always deflects in the same direction regardless of the direction of the current, as the heating effect of a current is independent of the direction of the current

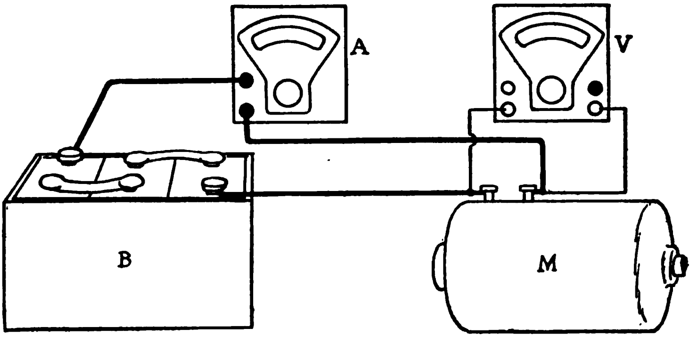


Fig. 283—*Connections of ammeter shunt in parallel with coil of ammeter* through the part of the circuit being heated. An instrument of this kind may be used in measuring either direct or alternating current.

Ammeter Shunts

In certain types of ammeters, especially the D'Arsonval type, it is practically impossible to carry the total current to be measured through the coil of the instrument. To prevent the necessity of doing this, use is made of what is called an ammeter shunt. This shunt is nothing more or less than a low resistance, arranged to be connected in parallel with the coil of the instrument. In other words, the coil of the instrument and the shunt are in parallel and the total current divides inversely as the resistance of the two paths. This shunt may be connected permanently and inclosed in the instrument case or it may be outside the instrument proper and connected to the coil of the instrument by flexible leads. When the outside method of connecting the shunt and coil in parallel is used, shunts of different resistances may be used with the same coil and in this way the range of the current capacity of the instrument, increased. When shunts are used the reading of the ammeter scale will be correct for one particular shunt, but additional markings must be provided, or the reading multiplied by a constant, for the other shunts. The current ranges for the different shunts are usually multiples of ten.

The resistance of the coil in the different types of ammeters should always be as low as possible in order that the voltage required to overcome the resistance of the ammeter be as low as possible. The coil when in parallel with the shunt gives a lower total resistance than the coil alone. The proper connection of an ammeter with an inclosed shunt is shown at A in Fig. 283. The ammeter indicates the current taken by the motor M and the current in the voltmeter, which is very small and usually may be neglected without any appreciable error.

Principle of the Voltmeter

The voltmeter is an instrument for measuring the electrical pressure between two points to which the terminals of the voltmeter are connected. The fundamental principle upon which the voltmeter operates is exactly the same as that of the ammeter, the difference being in the resistance of the instrument. The deflection of the pointer on an ammeter depends on the current through the windings of the instrument, and this current will vary in value as the electrical pressure acting on the instrument varies in value, provided the resistance of the instrument is constant. Thus, if an electrical pressure of 1 volt produces sufficient current in the winding of the instrument to cause the pointer to move a certain distance over the scale, then 100 volts will cause the pointer to move the same distance if the resistance of the instrument is increased to 100 times its original value. If the resistance be increased to ten times its original value, then ten times the electrical pressure will be required to produce a certain deflection, etc. With a certain resistance in circuit, the deflection of the pointer will vary as the pressure between the terminals of the instrument, because this variation in pressure causes the current through the instrument to vary in value.

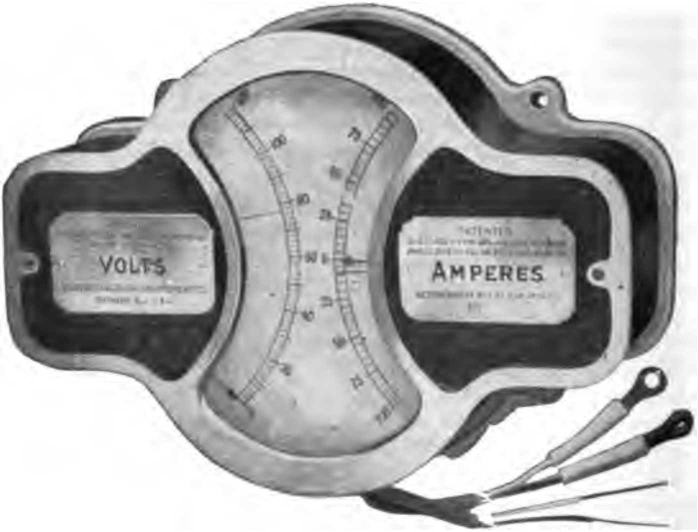


Fig. 284—Weston duplex instrument for electric motor cars, a combined ammeter and voltmeter

An instrument similar to the one shown in Fig. 278 may be changed from an ammeter to a voltmeter by changing the number of wires in the coil. Thus, if a current of 10 amp. is required to produce a certain deflection of the pointer when the instrument is used as an ammeter, the same deflection may be produced by sending a much smaller current through a larger number of wires when it is used as a voltmeter. The same thing is true of the instruments shown in Figs. 278 and 280.

The proper connections of a voltmeter are shown at V in Fig. 283.

Combined Ammeters and Voltmeters

Quite often an ammeter and a voltmeter are combined in a single instrument, which usually is spoken of as a duplex instrument. Such an instrument is shown in Fig. 284. In the duplex instrument the ammeter and the voltmeter, so far as their operation is concerned, are independent of each other.

In some cases the same coil is used either as an ammeter or as a voltmeter. The internal connections of an instrument of this kind are shown diagrammatically in Fig. 285. The terminal marked plus, +, is used both for the ammeter and the voltmeter. When connections are made to the plus terminal and the terminal marked 30 A, the instrument will read a maximum current of 30 amps. Changing from the 30 A terminal to the 3 A terminal, the maximum current will be 3 amp. When connections are made to the plus and 15 V terminals, a maximum pressure of 15 volts may be had, provided the key is depressed.

In some cases a charge and discharge indicator is used instead of an ammeter. The operation of these devices is very similar to the instrument shown in Fig. 278, which usually is referred to as the soft iron instrument. When the current passes through the coil in one direction, the moving part is turned in one direction, and with a reversal of current the moving part is turned in the opposite direction. The words ''charge'' and ''discharge'' appear when the moving part is in its entrance position. An indicator of this kind is shown in Fig. 286.

The Leece-Neville Co. manufactures an indicator which is a part of the cutout. A small target is attached to the armature of the cutout, and the position of the cutout is indicated by this target, which appears through an opening on the front of the case. The complete device is shown in Fig. 287.

Ampere-hour Meter

The ampere-hour meter is an instrument for measuring the quantity of electricity passing through an electrical circuit in a certain time. It usually consists of a rotating part connected to a system of gearing which operates one or more pointers that move over the dial on the front of the instrument. The construction and operation of the rotating portion is such that the rate at which it revolves varies directly as the current through the instrument. Thus if a current of 10 amp. causes the rotating part to make 1800 revolutions in one hour, then a current of 20 amp. will cause it to make 3600 revolutions in one hour. Now 10 amp. for an hour is 10 amp.-hrs. and 20 amp. for an hour is 20 amp.-hrs., etc. The gears connecting the rotating part and the pointers and markings on the dial should be such that each division on the dial corresponds to a definite number of ampere-hours. In some types of ampere-hour meters there is a difference in the rate at which the rotating portion revolves when the current through the instrument is reversed. This difference in the indication for the two directions of current may be varied, which permits the loss in a storage battery that is being charged and discharged through the ampere-hour meter to be taken care of. Thus the adjustment on charge may be such that the instrument reads 20 per cent slow and correct on dis-

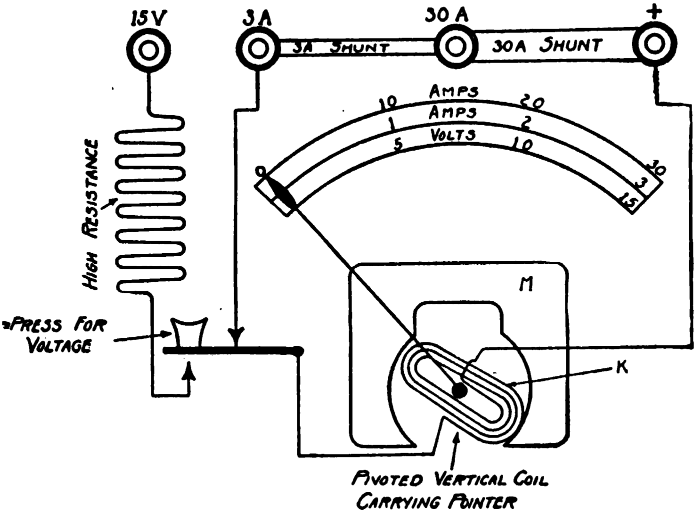


Fig. 285—*Diagram of combined ammeter and voltmeter in which the same coil is used as either instrument* charge. In such a case the battery input as shown on the dial of the ampere-hour meter would be the same as the battery output. A typical form of ampere-hour meter is shown in Fig. 288.

Wattmeter

The wattmeter is an instrument for measuring power, and briefly it is a combination of an ammeter and a voltmeter. One coil, or set of terminals, is connected in series in the circuit just as an ammeter is connected, and the other set of terminals is connected across the circuit just as a voltmeter is connected. The operation of the instrument is such that the deflection of the pointer is proportional to the product of the current in one coil and the electrical pressure applied to the terminals of the other coil, which gives the power in watts.

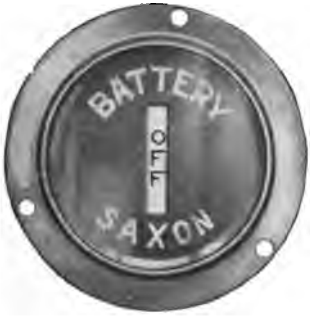


Fig. 286—Battery indicator

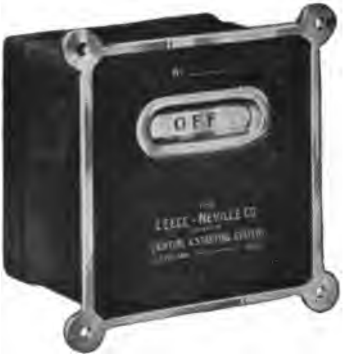


Fig. 287—Leece-Neville indicator

Watthour Meter

The watthour meter is an instrument for measuring the total energy passing a given point in an electrical circuit. It consists of a rotating portion whose rate of rotation is proportional to the power in watts. The rotating portion causes one or more pointers to move over one or more dials by a system of gears. This system of gears and the markings on the dials are such that the pointers on the dials give a reading of the energy in watthours or kilowatt hours. In the majority of cases the difference in two readings are taken for a period of approximately a month.

CHAPTER XXI

Ignition Systems

THE ignition system of a modern motor car engine constitutes one of the most important elements of the engine and one which is absolutely necessary in order to insure engine operation. Its primary object is to afford a means of kindling or setting on fire the compressed mixture of gasoline, gas and air in the engine cylinder, and thus produce what is called an explosion.

Early Methods of Ignition

The early systems of ignition were quite different from those in use at the present time and a brief description of several of them will be given in the following paragraphs.

Fig. 288—*Ampere-hour meter*

In the earliest forms of the gas engine, a flame burned near a valve in the head of the engine cylinder, and when the piston was in the proper position, the valve opened, thus permitting the flame to ignite the gas back of the engine piston. This method was used in the forms of engines in which the gas and air mixture was not compressed.

It was later found desirable to compress the gas and air mixture before exploding it and in such a case the open flame could not be used. A platinum tube was inserted in the side of the combustion chamber and this tube was heated to such an extent by means of a flame directed against its walls from the outside of the cylinder that the end inside the combustion chamber was maintained at a sufficiently high temperature to ignite the gas mixture.

Later forms used the property of gases to fire or ignite themselves if compressed to a sufficient degree, and others made use of the stored heat in the cylinder walls and head to fire the highly compressed charge.

All of these various methods were not practical in their application to the gasoline engine as used on the modern motor car, due principally to the fact that they did not permit a flexible engine action which is essential in a good motor car engine. The electrical ignition systems are standard at the present time and the fundamental principles upon which they operate will be discussed in the following section.

Low-Tension Ignition System

A low-tension ignition system is one using an electric arc which is produced by a low voltage or pressure. In a system of this kind the spark is produced within the cylinder by breaking the electrical circuit between two pionts in the combustion chamber, called electrodes. The principle of this system is shown diagrammatically in Fig. 289. When the igniter contacts are closed in the combustion chamber of the cylinder, a current will be produced in the circuit by means of the storage battery. After the engine shaft revolves a small angle, the contact in the combustion chamber is broken and when this break takes place, there will be an electric arc produced between the two parts of the igniter. A coil of wire about an iron core is shown connected in series in the circuit. This coil has a strong magnetic field produced about it and through its center when a current is established in the winding. This magnetic field represents a certain amount of stored energy just as a wound-up clock spring, and when the circuit is broken, the energy stored in the magnetic field will take some other force. As the magnetic field surrounding the coil decreases in value, due to a decrease in the current in the coil, the lines of magnetic force which are supposed to constitute the magnetic field cut the various turns of wire forming the coil, and as a result there will be an electrical pressure produced in the winding of the coil. This pressure may be and usually is many times the value of the pressure produced by the battery and as a result it tends to maintain the arc between the two terminals of the igniter when the circuit is broken in the combustion chamber. The purpose of the coil then is to give a much hotter and longer spark than would otherwise be obtained. Such a coil, of course, has only one winding and they are usually called primary or low-tension coils. The application of an ignition system of this kind to a four-cylinder engine is shown diagrammatically in Fig. 290. In this case the source of electrical energy is either the magneto or the five dry cells, depending upon the position in which the ignition switch is thrown.

The chief advantage of the low-tension ignition system is its freedom from short-circuits caused by poor insulation of the electrical circuit. This system of ignition, however, is of only historical interest so far as the motor car is concerned, as it has been discarded for several years and is now confined almost entirely to low-speed stationary engines.

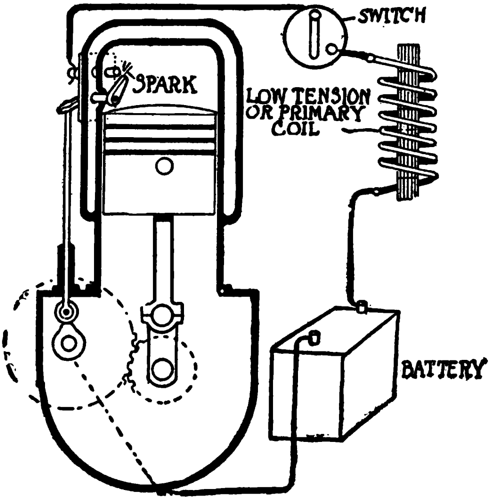


Fig. 289—*Principle of low-tension ignition*

This system is commonly called the make-and-break system of ignition.

High-Tension Ignition System

The operation of the high-tension ignition system is based on the fact that when a sufficiently big electrical pressure is made to act upon an electric circuit in which there is a small gap, the electricity will leap this gap and produce a small arc. The principal parts of a high-tension ignition system are shown diagrammatically in Fig. 291. B is a source of electrical energy such as a battery or low-tension magneto connected in series with the primary winding P of the ignition coil, the vibrator V and the contactor C. The contact C is operated by the engine so that it makes contact at the exact time an ignition spark is required in the engine cylinder.

When the contact C is closed, a current will be produced in the primary winding of the coil which magnetizes the iron core and the vibrator V is attracted to the core. When the blade V moves away from the end of the adjusting screw, the primary circuit is opened and the iron core is demagnetized and the vibrator returns to its original position, and this operation is again repeated in rapid succession so long as the contact C remains closed. Each time the current in the primary circuit is established and destroyed, there is a high electrical pressure produced in the secondary winding. This high electrical pressure is of sufficient value to cause a current to be established between the terminals or electrodes of the spark plug, and thus produce the desired ignition spark.

A four-cylinder combination is shown diagrammatically in Fig. 292. Two batteries are provided in this case and either one may be used by throwing the switch on either point 1 or point 2.

This system is sometimes called the jump-spark system.

If a current of electricity be established in a wire there will be a magnetic field produced about the wire. The strength of the magnetic field will depend upon the value of the current in the wire, and its direction will depend upon the direction of the current in the wire. Any change in the value of the current in the wire will result in a change in the strength of the magnetic field, it increasing with an increase in the value of the current and decreasing with a decrease in the value of the current. A reversal in the direction of the current will result in a change in the direction of the magnetic field.

Now if the wire be formed into a coil as shown in Fig. 293, a much stronger magnetic field will be produced inside the coil than was originally produced near the straight wire. Inserting an iron core inside the coil will increase the number of magnetic lines passing through the coil due to the fact that iron is a better conductor of magnetism than air, just as copper is a better conductor of electricity than iron.

Let us now investigate what will happen when such a coil is connected or suddenly disconnected from a source of electrical energy such as a storage battery. Just at the instant that the circuit is closed, the current starts to increase in value at a very high rate, but it cannot reach its maximum constant value, which is equal to the electrical pressure divided by the resistance, in zero time for the following reason: As soon as there is any current at all in the wire there will be a magnetic field produced and this magnetic field will increase in strength as the current in the wire increases. While the magnetic field is increasing, the magnetic lines through the coil are increasing in number and an electrical pressure is set up in the

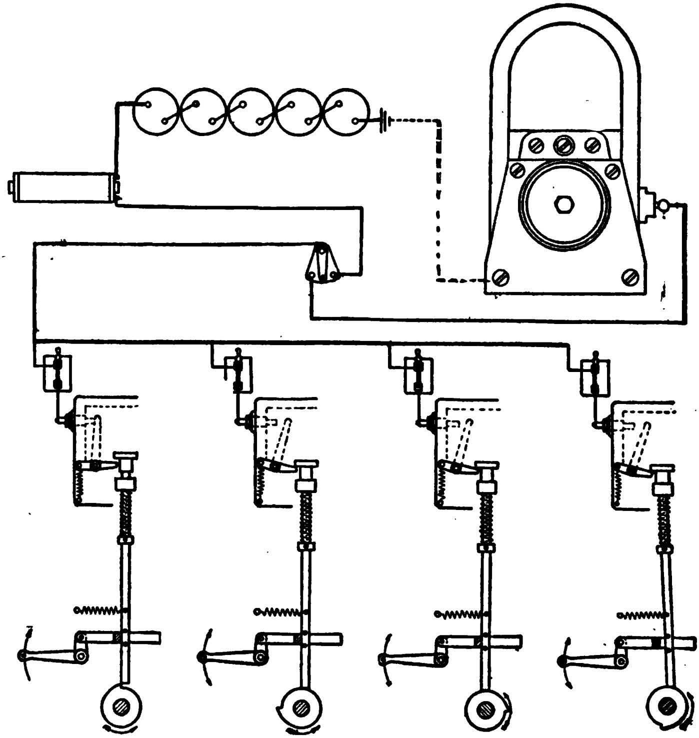


Fig. 290—*Four-cylinder, low-tension ignition system*

various turns of the coil whose direction in the circuit is just the reverse of the electrical pressure of the battery or other outside source of pressure producing the current. As a result of this pressure being produced in the circuit and since its direction is opposite to the direction of the current, the current will not build up in value as rapidly as it would if there were no pressure being produced. When such a circuit is opened there will be an electrical pressure produced, but its direction will be just the reverse of what it was when the circuit was closed or its direction will correspond to the direction of the current. Thus, this electrical pressure produced in a circuit due to any change in the value of the current in the circuit is always in such a direction as to tend to prevent any change taking place in the value of the current. An electrical circuit in which there is an electrical pressure produced when there is a change of current in the circuit is said to possess self-inductance. The value

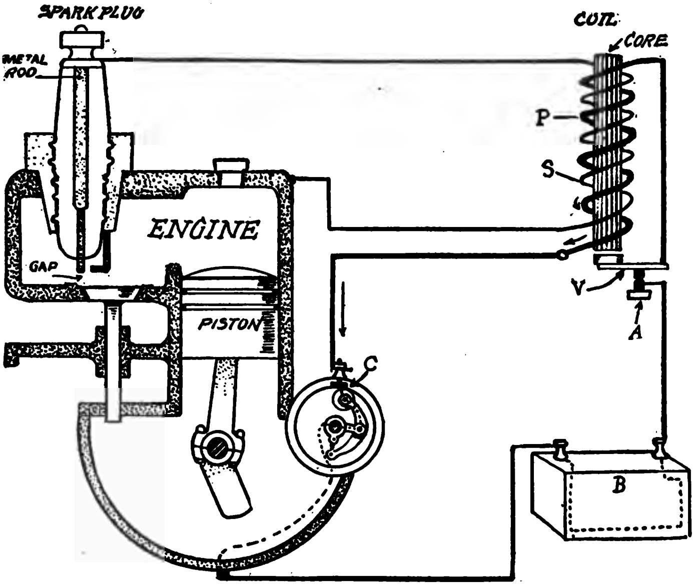


Fig. 291—*Principle of high-tension ignition* of the self-inductance of a coil will depend upon the number of turns in the coil, the size of the turns, the length of the coil and the kind of material forming the core.

If an electrical circuit containing considerable self-inductance be quickly opened, there will be a tendency for the current to drop to zero value instantly, which would result in the magnetic field about the circuit being destroyed in a like time. This change in circuit and magnetic field does not take place instantly, because, as the magnetic field decreases in value there is a pressure produced which tends to maintain or prolong the current. The value of this pressure may be many times the value of the pressure of the source of energy and as a result it will be ample to maintain an electric arc between the two points where the circuit is being broken. The duration of this high pressure is determined by the time required for the magnetic field to be reduced to zero value.

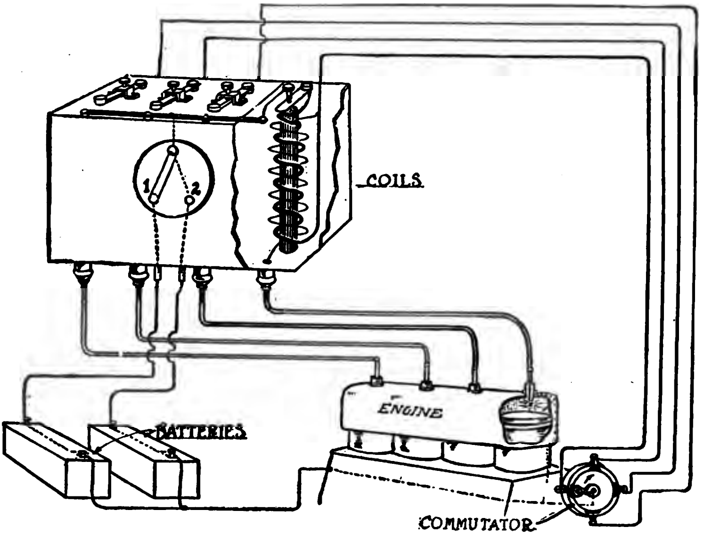


Fig. 292—*Four-cylinder, high-tension ignition system*

The rapidity with which the current in a circuit containing inductance builds up in value when the circuit is closed and decreases in value when the circuit is opened depends upon the relation between the inductance of the circuit and the resistance of the circuit. The larger the resistance and the smaller the inductance, the less the time required for a certain change in the value of the current to take place. Thus the current in a certain circuit might build up in accordance with the curve, A, shown in Fig. 294, in which the height of the curve above the horizontal represents the value of the current, and the distance along the horizontal corresponds to time. If the resistance of the circuit be increased the current will rise in value more rapidly, but it will, however, not reach as high a maximum value. The operation of the coil may be such that the circuit is closed only for the time, T, as shown in figure and in such a case the value of the current in the circuit with the resistance in series will be greater than without the resistance. Hence it is sometimes possible to improve the operation of a coil by placing a resistance in series with it and thus increase the rapidity with which the current builds up. The effect of the resistance on the decay of the current is to cause the current to drop off in value more rapidly.

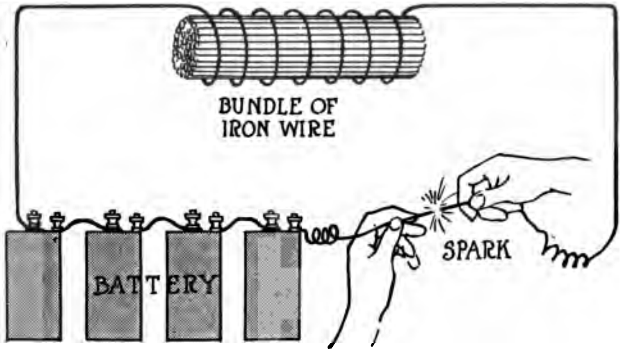


Fig. 293—Illustration of principle of make-and-break spark coil

The magnetic field surrounding the coil represents a certain amount of stored energy and it is this energy which is transformed into electrical energy when the circuit is broken, and then in turn converted into heat in the electric arc at the point of break. The greater the inductance of the coil and the larger the value of the current the greater the amount of energy stored in the magnetic field. There is, however, a limit to the amount of energy required in the spark and it is not economy to design the coil so as greatly to exceed this value.

Fundamental Principles of Jump-Spark Coil

The construction of a typical jump-spark coil is shown in Fig. 295. It consists of two coils about an iron core. One of these coils, called the primary, is connected in series with a source of energy and a vibrator similar in principle to those used on an electric door bell.

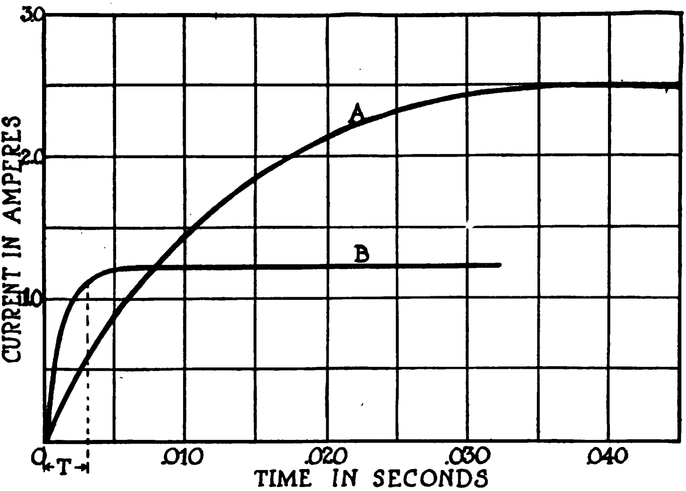


Fig. 294—Curves showing the relation between current and time in an inductive circuit while current is increasing

The second coil, called the secondary, is wound outside the primary and it consists of a relatively large number of turns as compared to the primary and of much smaller wire.

Any variation in current in the primary winding will cause a change in the magnetic field within the secondary winding which will result in an electrical pressure being produced in the secondary winding while the change in magnetic field is taking place. In the operation of the coil, the circuit is controlled by a contact which in turn is opened and closed at a definite time in relation to the position of the piston in the cylinder of the engine. When this contact is closed, the current immediately builds up in the primary winding and of course magnetizes the soft-iron core. The iron core then attracts the iron armature or hammer, and it is drawn toward the core, which causes the electrical circuit to be opened at the contact on the end of contact screw. As soon as the primary circuit is opened, the armature returns to its normal position, since there is not sufficient current to magnetize the iron core. Just as soon, however, as the electrical current is again closed at the end of the contact screw, assuming the other contacts are closed, the above operation will be repeated. Many cycles of this operation may be completed during the time the contact in the primary which is controlled by the gas engine—the timer—is closed.

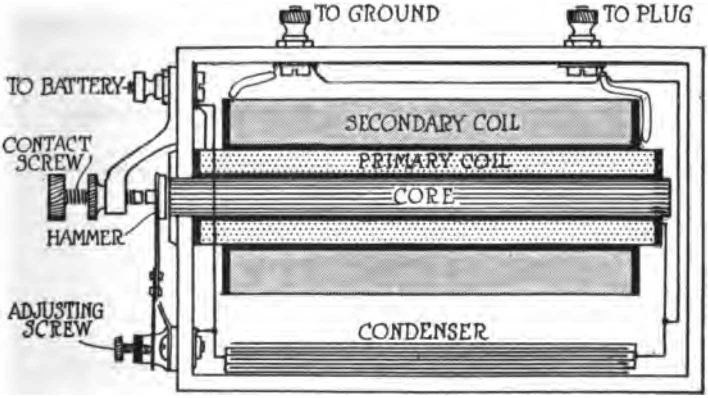


Fig. 295—*Construction of typical jump-spark coil*

While the magnetic field within the secondary winding, due to the primary current, is building up in value, there will be an electrical pressure produced in the secondary winding and its direction will be such as to produce a current which tends to oppose the change in the magnetic field. Likewise, when the magnetic field in the secondary is decreasing in value, there will be an electrical pressure produced and its direction will be such as to produce a current which tends to oppose any change in the magnetic field. It is thus seen that the building up and decaying of the current in the primary winding causes an alternating pressure to be produced in the secondary winding. The value of this pressure in the secondary will depend upon how rapidly the magnetic field is changing and the number of turns in the secondary winding. The change in the magnetic field depends upon the time constant of the primary winding, that is, the relation between the inductance and the resistance of the primary winding. The more rapidly this magnetic field can be changed in value, the greater the pressure induced in the secondary winding.

Purpose of Condenser in Jump-Spark Coil

The condenser used in combination with a jump-spark coil acts as an electrical shock absorber. It is connected across the breaker contacts and when they open, the energy which would normally go into the arc is stored in the condenser, thus eliminating the serious troubles due to the arc. The current in the primary circuit is reduced to zero more quickly and a higher voltage is produced in the secondary winding.

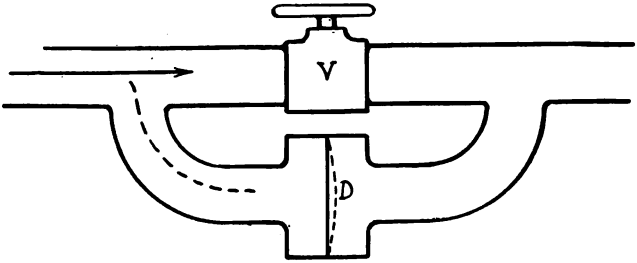


Fig. 296—Hydraulic analogy of the condenser across breaker contacts

The operation of the condenser might be compared to the operation of a diaphragm, D, stretched across a tank or pipe connected around a valve, V, as shown in Fig. 296. If the valve be suddenly closed the diaphragm relieves the strain on the valve to a great extent and thus allows the flow of liquid to be reduced to zero in a shorter time than it could be if no diaphragm were used.

CHAPTER XXII

The Magneto

EARLY forms of ignition devices depended upon the primary cell entirely as a source of electrical energy, but it was found to be inadequate to meet the requirement imposed upon it by the motor car manufacturers, who demanded as reliable a source of energy as it was possible to obtain. The use of the storage battery overcame some of the disadvantages of the primary cells, but the storage batteries had to be removed from the cars for charging. The storage battery, however, did not satisfactorily meet the demands, and as a result the magneto was developed and applied to the motor car engine. Later, how-

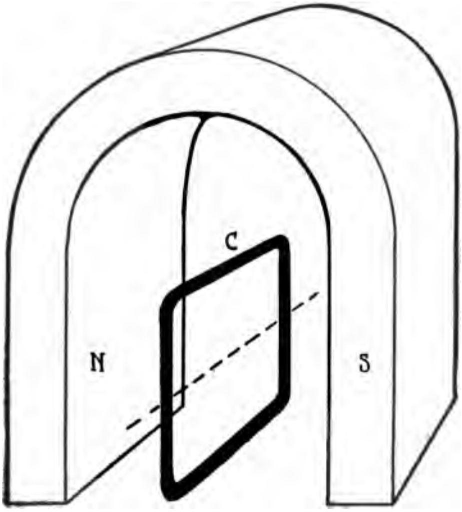


Fig. 297—Fundamental principle of the magneto

ever, suitable charging generators and regulating devices were developed, by which the storage battery could be kept in a condition of charge without being removed from the car, and it is at present used as widely as any source of electrical energy for motor car engine ignition.

Fundamental Principle of Magneto

The fundamental principle upon which the magneto operates may be explained by reference to Fig. 297. A magnetic field is produced between the poles N and S of a strong permanent magnet. A coil of wire C is mounted on a suitable shaft so that it may be revolved in the magnetic field of the magnet. Now, as the coil of wire revolves the magnetic lines of force which are supposed to form the magnetic field will be cut by the sides of the coil and as a result an electrical pressure will be produced in each of the two halves of each turn of the coil. The value of this pressure in any one of the wires at any instant will depend upon the rapidity with which the wire is moving across the magnetic lines in a direction perpendicular to them and also upon the strength of the magnetic field or the number of lines of magnetic force per square centimeter. An inspection of the figure will show that the two sides of each of the turns are moving parallel to the direction

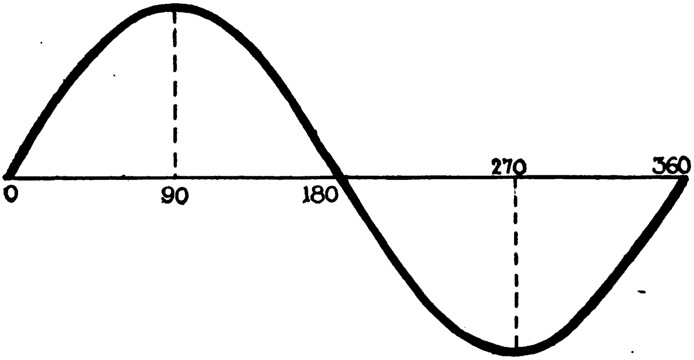


Fig. 298—*Curve showing variation in value of electrical pressure produced in coil revolved in a uniform magnetic field* of the magnetic field when the plane of the coil is vertical, and hence when the coil is in this position no electrical pressure will be produced in it. When the plane of the coil is parallel to the direction of the magnetic field the two sides of each turn are moving perpendicular to the direction of the magnetic lines, and hence the lines of force are being cut at the greatest rate. It is interesting to note that the actual number of lines of magnetic force through the coil is at a maximum when the rate at which the sides of the coil are cutting the lines of force is at a minimum, and also that the actual number of lines of force through the coil is at a minimum of zero when the rate of cutting is at a maximum, or the sides of the coil are moving perpendicular to the direction of the magnetic field.

For positions intermediate between those referred to in the preceding lines the value of the electrical pressure in the winding coil will depend upon the angular position of the coil with respect to a reference plane parallel or perpendicular to the magnetic field. The total pressure produced in the coil at any instant will be equal to the sum of the pressures produced in the several turns of the coil. The variation in value of this total pressure may be represented graphically by a curve, such as the arc shown in Fig. 298. The distance along the horizontal corresponds to the magnetic field, and the distance of the curve above or below the horizontal line corresponds to the value of the electrical pressure in the coil. The direction of the electrical pressure in the coil will change during the rotation of the coil as the movement of the two sides with respect to the magnetic

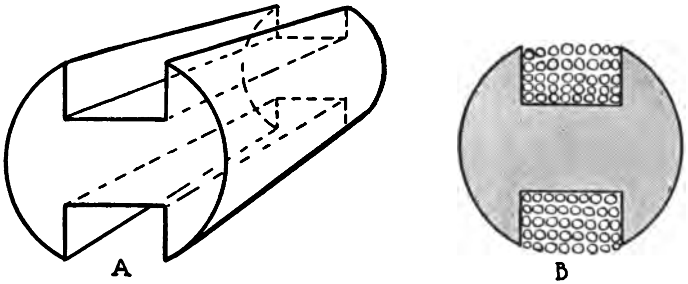


Fig. 299—*Iron core for magneto*

field changes. This change takes place when the electrical pressure in the coil is zero. The electrical pressure is said to be positive for half a revolution and negative for half a revolution. It must be understood that these terms are only relative, and either part of the curve above or below may be considered the positive portion and the other part the negative portion, but it is common practice to think of the upper portion as being positive and the lower portion negative.

An electrical pressure of this kind is called an alternative pressure on account of its reversing in direction, and it would produce an alternating current if it were to act on a closed electrical circuit.

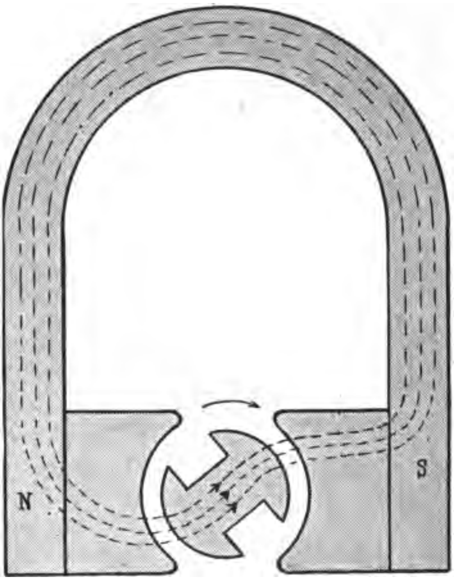


Fig. 300—*Cross section of magnetic circuit of magneto*

The time required to complete one cycle is called the period. Thus the period of a sixty-cycle current or pressure is $\frac{1}{16}$ sec.

Each of the individual sets of positive and negative values is called an alternation.

Simple Form of Magneto

In the construction of the magneto the coil of wire is wound on an iron coil similar in form to the one shown at A in Fig. 299. A cross-section through the iron core and coil is shown at B in the same figure. The iron core is mounted between pole pieces fastened to the poles of strong permanent magnets. Two cross-sections of the magnetic circuit are shown in Figs. 300 and 301 respectively. With this construction the rate at which the magnetic lines are cut is quite different from the case shown in Fig. 297. The magnetic lines seem to be carried around with the iron core toward the trailing tips of the pole pieces, as shown in Fig.

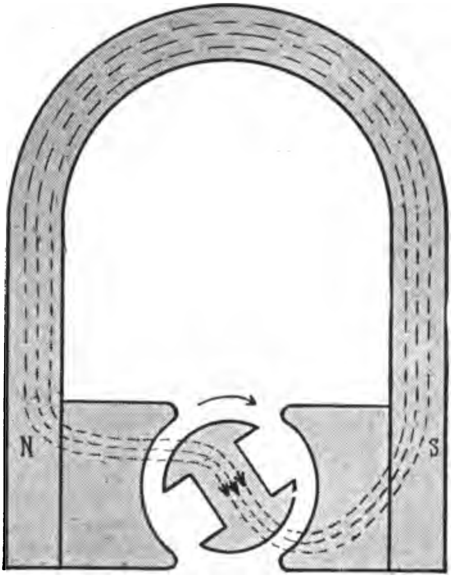


Fig. 301— *Cross section of magnetic circuit of magneto*

300, and they then rather quickly change their direction through the coil around the core as shown in Fig. 301. The sudden change in the number of lines of force through the coil results in a high electrical pressure being produced in the ending of the coil. This high electrical pressure is as a rule quite desirable, as will be explained later.

Four different positions of the iron core are shown in Fig. 302, and directly beneath them is shown a curve which represents the variation in the electrical pressure for all positions of the core.

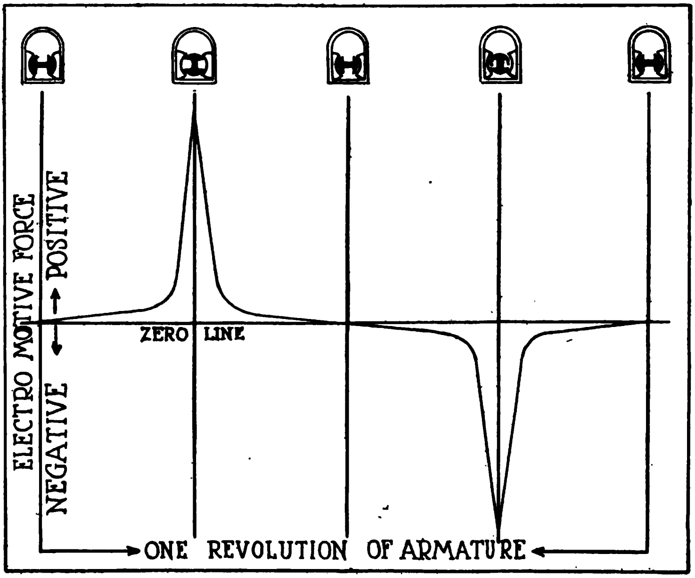


Fig. 302—*Variation in electrical pressure of magneto for different positions of armature core*

The operation of the magneto as explained in the previous section depended upon the rotation of a coil of wire in a magnetic field, which resulted in the various turns of the coil cutting the magnetic lines of force forming the magnetic field, and this cutting of the magnetic lines resulted in an electrical pressure being produced in the coil. The same results could be obtained by allowing the coil to remain stationary and by some means increasing and decreasing, and perhaps building up, the magnetic field through the coil in the opposite direction. In this second case there would be a relative movement of the turns of the wire forming the coil and the magnetic field, and this is the principle upon which the inductor type of magneto operates.

The magnetic field is produced by strong permanent magnets, and a mass of iron is rotated between the poles of the magnets while the winding is stationary. A good example of a magneto of this kind is one manufactured by the K. W. Ignition Co. The moving element of the magneto is called the rotor, and it is shown assembled with the coil in position in Fig. 303. The winding is placed around the shaft and between two blocks of laminated iron. These blocks of iron are riveted to the shaft at right angles to each other. The pole pieces attached to the end of this permanent magneto are so shaped and placed in such a position that the magnetic lines in traveling across from one pole piece to the other find a path of low magnetic resistance, or reluctance, through the winding and one end of each of the masses of iron attached to the shaft. The value of the magnetic flux, or the num-

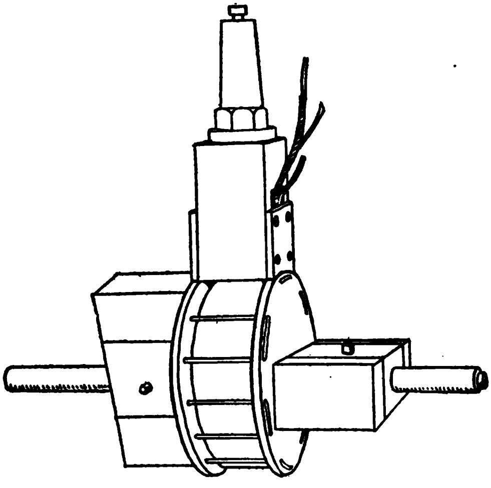


Fig. 303—Rotor and winding of K. W. magneto

ber of lines of magnetic force through the coil, will change as the reluctance of the path in which the magnetic lines travel changes, the flux increasing with a decrease in reluctance and decreasing with an increase in reluctance. Each quarter turn of the rotor, or each 90 deg., the direction of the magnetic flux through the coil will be reversed; consequently, an electrical wave of pressure equivalent to one-half cycle will be produced for each quarter turn of the rotor. A cross-section through a K. W. high-tension inductor type magneto is shown in Fig. 304.

Dixie Magneto

The operation of the Dixie magneto in some respects is somewhat similar to the inductor type, but in this case the pole pieces themselves revolve, and they do not reverse their polarity as in the case of the inductor type. The principle of the Dixie magneto may be understood easily by an inspection of Fig. 305. The pole pieces, as shown in the figure, are one-sided and mechanically connected by a non-magnetic section. Each pole piece will have the same polarity as the end of the permanent magnet immediately behind it. This arrangement results in two pieces of iron with opposite magnetic polarity revolving in a circle. A piece of iron in the shape of a letter V has its ends shaped to form an opening in which the pole pieces may revolve. A winding is placed about the bottom of this V-shaped piece of iron. Now, as the pole pieces

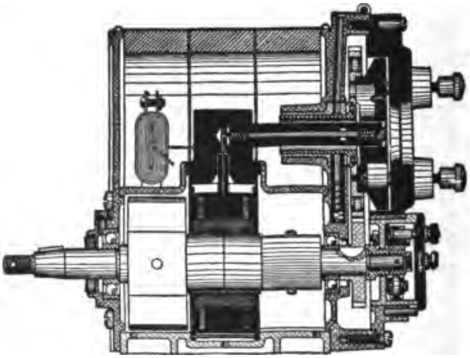


Fig. 304—*Cross-section of K. W. inductor type magneto* are caused to revolve, the magnetic poles pass the ends of the V-shaped piece, which causes the magnetic flux produced by these pole pieces to reverse in direction through the winding.

This magneto is unique in that the magnets are placed the reverse way of the usual custom, at right angles instead of parallel to the rotative axis.

Berkshire Magneto

The Berkshire magneto is a machine working on somewhat the same principle. Two cuts of this magneto are shown in Fig. 306. Referring to the figure, the two main poles of the magnets are A and B, while C and D are iron laminations running parallel to the armature as shown in the left-hand figure. The rotating armature is formed partly of iron and partly of aluminum. The iron parts are shown in black, and for the position of the armature shown in the figure the magnetic lines flow along the following path: From A to C through a portion of the armature, from C to D through the piece of laminated iron upon which the coil is wound, from D to B through another section of the armature and from B to A through the magneto. As the armature revolves and the iron parts come opposite the poles, instead of bridging the gap between them as sketched, there is no complete magnetic circuit through the core of the coil. This means that revolving the armature continually makes and breaks the magnetic circuit through the core of the coil.

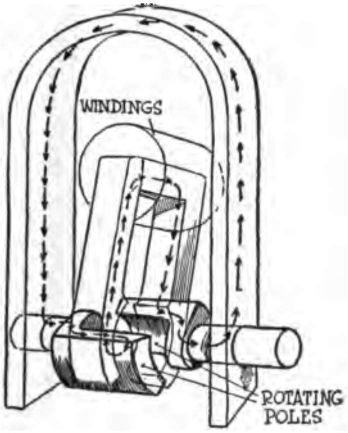


Fig. 305—*Path of magnetic flux in Dixie magneto*

Simms Magneto

A special feature of the magneto made by the Simms Magneto Co. is the design of the pole pieces, which have extensions on the edges following the direction of rotation of the armature. These extended edges keep the edges of the armature shuttle within the influence of the pole pieces for all positions from full retard to full advance. This results in the shuttle never being widely separated from the pole pieces when the current is broken. The shape of these pole pieces is shown in Fig. 307.

Mea Magneto

The magnets in the Mea magneto, instead of being of horseshoe form, are bell-shaped, as shown in Fig. 308. The entire magnet is carried in a trunnion mounting so that the field magnets may be turned to the same extent that the contact breaker is turned to give the necessary advance or retard of the spark, thus insuring that the circuit will be broken with the armature in the same relative position with respect to the field poles.

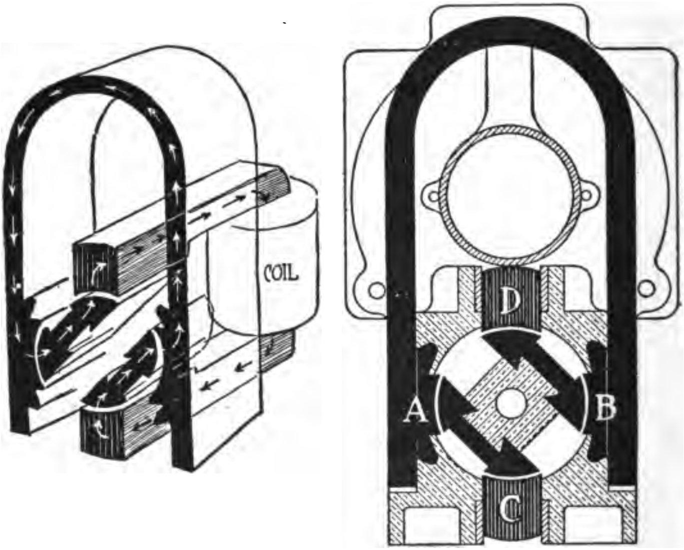


Fig. 306—*Berkshire magneto, which works on somewhat the same principle as the Dixie*

The method whereby this is accomplished is shown in Fig. 309. The relative position of the armature and field magnets are shown for both the full retarded and advanced positions of the spark. The movement of the magnets is against the direction of rotation of the armature when advancing the spark and in the direction of rotation of the armature when retarding the spark.

Low-Tension Magneto

The low-tension magneto, as its name indicates, is one in which an electrical pressure of relatively low value is produced when the armature of the magneto is driven at ordinary, or working, speed. The winding of this type of magneto consists of a single coil of rather large wire, something like a No. 18 Bandsgage. The volume of current such a magneto is capable of supplying is, of course, greater than the current a high-tension type can supply, but this current is supplied at a relatively low voltage, so that the actual output of the two types of magneto may be practically the same. The low-tension magneto is used with the make-and-break system of ignition its winding being connected directly in series with the ignitor points and, perhaps, an inductive coil, sometimes called a kick coil, which intensifies the spark.

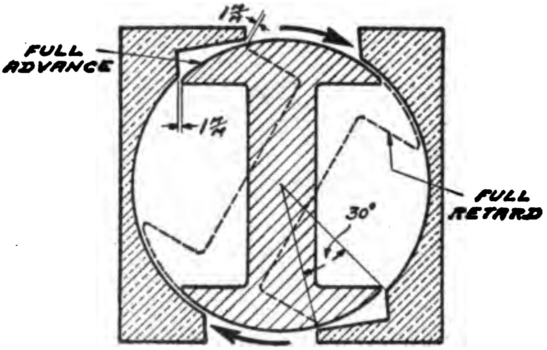


Fig. 307—*Shape of pole pieces for Simms magneto*

Since the electrical pressure generated in the winding of the low-tension magneto is so low, it is impossible to use such a magneto with jump-spark ignition systems without increasing the voltage by an induction coil. Magnetos of the low-tension type then always are used with all induction, just as the battery is combined with the induction coil, when they are used in supplying current for jump-spark systems of ignition.

The application of the low-tension magneto is shown diagrammatically in Fig. 310. A sectional view of a low-tension magneto is shown in Fig. 311. Each of the most important parts is given its proper name.

The purpose of the high-tension distributor shown in Fig. 310 and 311 is to distribute the high-tension current from the high-tension coil, shown at the right of Fig. 310, to various spark plugs when the interrupter breaks the primary circuit of the coil, which includes the winding of the magneto. The distributor brush should be making contact with or directly opposite one of the segements connected to the spark plug wire terminals when the primary circuit of the high-tension coil is broken. The distributor usually is mounted on the magneto and geared to the armature shaft in order that the position of the distributor arm and the cam, relative to each other in their respective cycles of operation, be practically the same, except for the advancing or retarding of the spark.

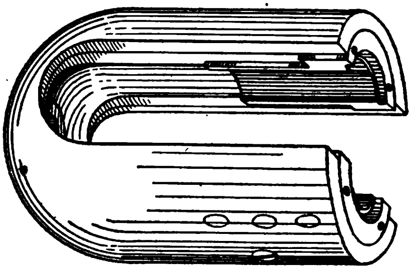


Fig. 308—*Bell-shaped magnet for Mea magneto*

As the cam on the end of the armature shaft shown in Fig. 311 rotates, it raises the interrupter, or breaker arm, A, twice each revolution, and this causes the primary circuit of the high-tension coil to be opened suddenly, which results in a high electrical pressure being induced in the secondary winding, provided the break in the primary circuit occurs when the armature is in such a position as to have a rather high electrical pressure induced in its winding. In a four-cylinder, four-cycle engine, four sparks are required every two revolutions of the engine crank; hence, the distributor will be driven at half the speed of the engine crank. Since only two sparks are possible with this type of magneto for each revolution of the armature, it is necessary to drive the armature at twice the speed of the distributor, or at engine speed. In a six-cylinder engine, the distributor shaft revolves at half the engine speed, and the armature shaft at one and one-half engine speed in order that the required six sparks be produced for each two revolutions of the engine crank.

High-Tension Magneto

The high-tension magneto differs from the low-tension magneto in only a few particulars. The armature on the high-tension magneto is so wound that a high-tension current may be obtained from it without the use of a separate induction or high-tension coil. In some types, this high-tension current is produced in an armature winding of many more turns than is provided in the ordinary low-tension magneto, while in other types a second winding is placed around the first, which serves the same purpose as the secondary winding of the high-tension coil. This secondary winding is insulated carefully from the primary winding, except at one end, where both it and the primary winding are grounded. A cross-section of a typical high-tension magneto is shown in Fig. 312. PW is the primary winding, and SW is the secondary winding. The insulated end of the secondary winding is insulated carefully and connected to a metal collector ring, O, mounted on the armature shaft, and a small carbon brush, resting on this collector ring, takes off the secondary current and leads it to the distributor brush, Z. A cross-section perpendicular to the armature shaft is shown in Fig. 313. A simplified diagram of the circuits of a high-tension magneto is shown in Fig. 314. The two metal points of the contact breaker normally are in contact. As the cam rotates one end of the bell crank comes into contact with

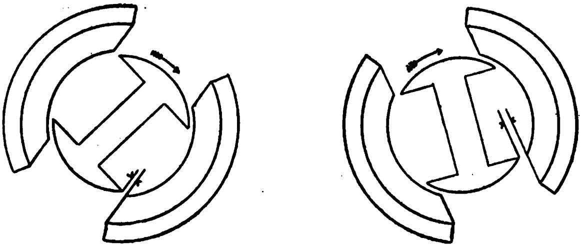


Fig. 309—Relative position of armature and magnets for different postions of spark in Mea magneto

an extension on the cam, which causes the bell crank to rotate, and, as a result, the two contacts are separated momentarily. The primary circuit thus is opened and closed as many times for each revolution of the cam as there are projections on the cam.

When the primary circuit is opened suddenly, an action will be taking place in the secondary winding, very similar to that taking place in the ordinary high-tension coil. At the same time there is a change in the magnetic lines of force through the secondary winding, due to a change of current in the number of magnetic lines, which, in turn, is due to the rotation of the armature in the magnetic field, which serves to increase the action taking place in the secondary winding.

The purpose of the condenser, J, in Fig. 312 is to cause the current in the primary winding to decrease in value in a shorter time when the primary circuit is opened than it would otherwise, and at the same time to reduce greatly the amount of arcing at the breaker contact points. In some types of magnetos this condenser is mounted inside the magneto armature, while in other types it is outside the armature.

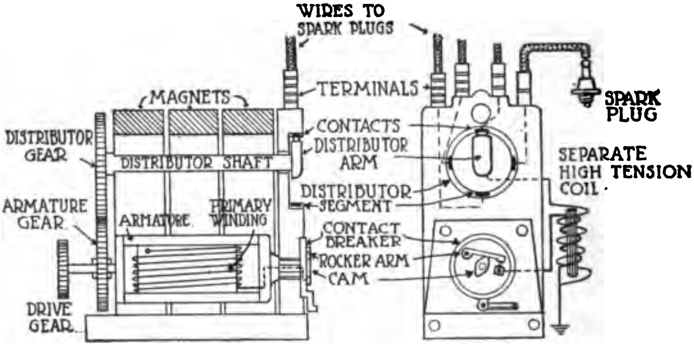


Fig. 310—*Application of low-tension magneto, in which a high-tension distributor is used*

Safety Gap

A device called a safety gap is provided on high-tension magnetos, whose function is somewhat similar to a safety valve. If, for example, one of the high-tension leads from the distributor

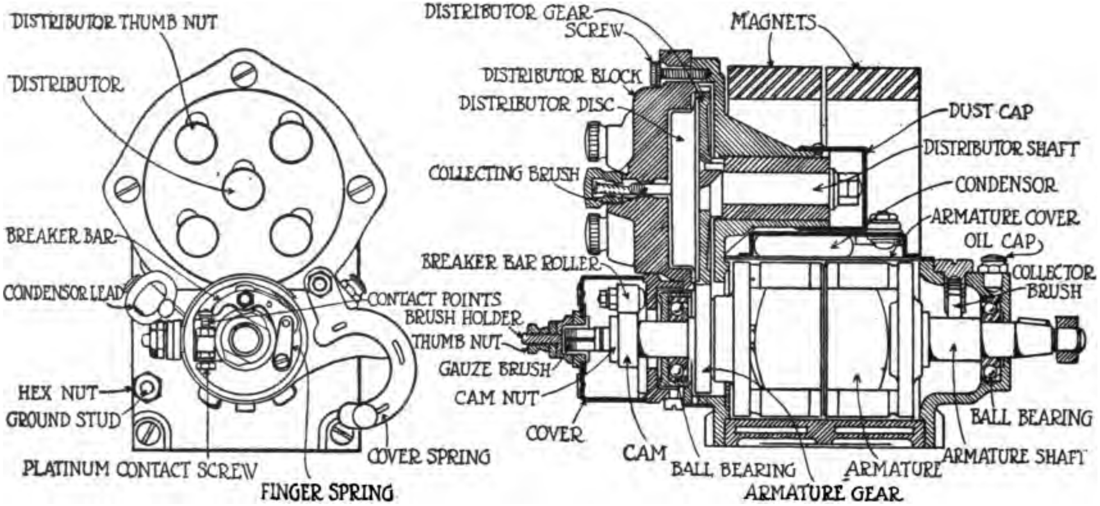


Fig. 311—Cross-section of Splitdorf low-tension magneto, with each important part given its proper name

to the spark plugs should become detached so that the path through which the high-tension current ordinarily would flow would be open, then a very high voltage would be acting on the insulation and the insulation might be damaged seriously unless some easier path be provided for it to escape through. A magneto, of course, must be capable of generating a hot spark at slow engine speeds, and this results in a very high voltage spark being produced at high engine speeds.

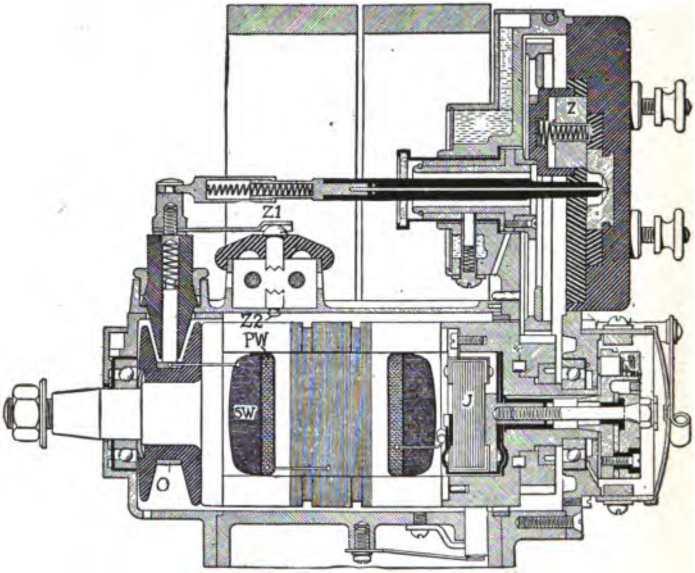


Fig. 312—*Longitudinal cross-section through typical high-tension magneto, parallel to armature shaft*

The value of the electrical pressure produced in the secondary winding is limited by the distance between the spark plug points and the degree of compression in the engine cylinder. If these points are not in circuit, as previously explained, due to a broken or loose secondary wire, or if they are loose or apart, a very high voltage will be induced in the secondary winding. The possibility of such a destructive high-tension voltage being generated in the secondary winding is prevented by connecting across the terminals of the secondary winding an auxiliary gap, as shown in Figs. 312 and 313. The gap between the two terminals Z1 and Z2 is longer than the gap between the terminals of the spark plug and ordinarily no spark will pass between these terminals, but should one of the secondary circuits from the distributor be opened accidentally the electrical pressure in the secondary winding will build up to a value just sufficient to jump the safety gap and no higher.

The V-shaped piece is so arranged that it may be turned through a small angle relative to the permanent magnets. The object of this is to obtain the same intensity of spark for all positions of the spark. Thus when the breaker is rotated by the spark lever in advancing or retarding the spark, the coil and piece of wire on which it is wound is rotated on the same turn and exactly the same amount so that the same magnetic conditions are maintained.

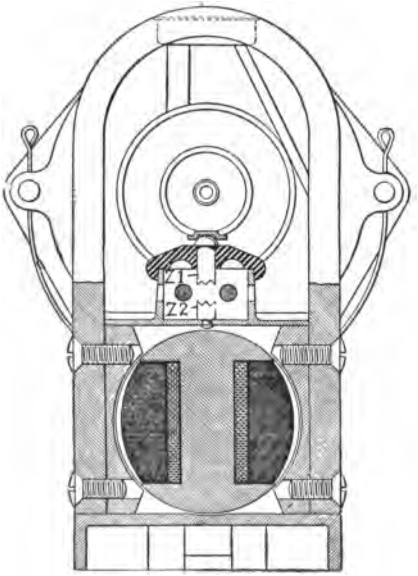


Fig. 313—Cross-section of typical high-tension magneto perpendicular to the armature shaft

Friction-Drive Magneto

The very early forms of magnetos were driven by a small friction wheel mounted on the end of the magneto shaft, and the magneto was so arranged and mounted that this wheel rested against the surface of some revolving portion of the engine, usually the flywheel. In these cases it was not necessary that there be any definite relation between the speed of the engine and the speed of the magneto. The principal difficulty was the dangers resulting from excessive speeds, and this was overcome by combining a governor with the friction wheel in such a way that the driving action ceased when the speed of the magneto armature exceeded a predetermined maximum for which the governor had been adjusted. A magneto fitted with a friction drive and governor is shown in Fig. 315. A belt sometimes is used in driving a magneto but in no case where the speed of the magneto and engine must bear a definite relation to each other.

Gear- and Chain-Drive Magnetos

In all cases when it is necessary that the speed of the magneto armature bear a definite relation to the speed of the engine shaft, it is necessary to make use of either the chain or gear methods of driving. Gear drive is used more than the chain drive, and the gears usually are made an integral part of the engine, or the same gears that are used in driving the pump or camshaft may be used in driving the magneto. Two typical methods of mounting and driving a magneto by gears are shown in Figs. 316 and 317. It is customary to mount the magneto on a bracket which is a part of the engine base or to provide a suitable mounting by bolting a bracket to the engine base. Several methods of fastening

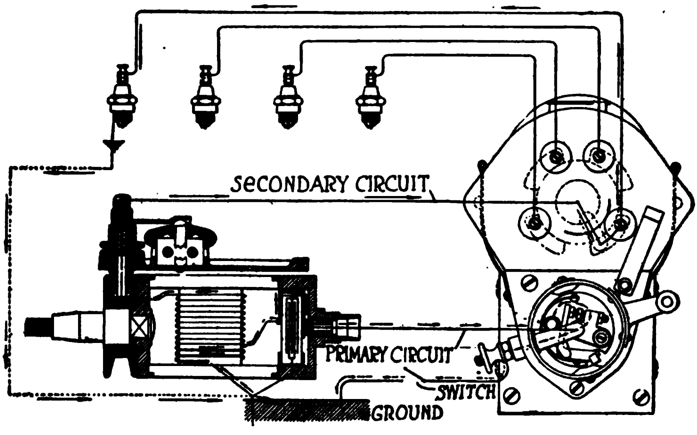


Fig. 314—*Simplified diagram of the circuits of a high-tension magneto* the magneto in position are shown in Fig. 318. It always is best when possible to place the magneto on the inlet side of the engine and as far away from the exhaust pipe as possible, because the excess heat is likely to seriously injure the insulation. A flexible coupling usually is provided between the magneto and driving shaft to take care of any slight improper alignment of the two with respect to each other.

When the magneto is driven by a chain, some means must be employed to keep the chain tight to keep the armature of the magneto and the engine shaft always in their proper relation.

Impulse Starters

The impulse starter is a special form of coupling which operates, in brief, as follows: The armature of the magneto is connected to the driving shaft by a spring, and in starting the magneto armature is prevented from rotating, which results in the connecting spring being compressed or wound up as the driving shaft rotates. After the driving shaft has revolved a certain angular distance, the armature of the magneto is released, and it jumps forward under the influence of the spring until it is caught again and the

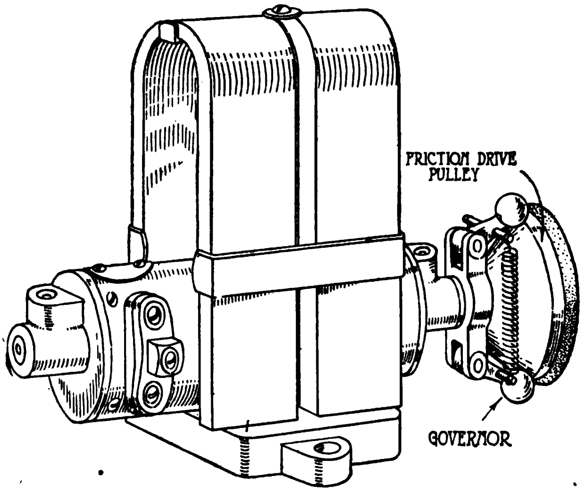


Fig. 315—*Friction-drive magneto with governor* cycle of operations repeated. During the rapid movement of the armature, the magnetic lines of force will be cut at a high rate, which will result in a high electrical pressure being produced in the armature winding. By properly connecting the magneto gears to the engine, this high electrical pressure may be produced just at the instant that a spark is desired in one of the cylinders.

The operation of a device of this kind as made by the Eisemann company may be explained by reference to the three cuts shown in Fig. 319. The coupling consists of two parts, a tube, A, which is the driving member, and an inclosing cup, B, which is the driven member, the two being connected by a spring. There is a loose ring, C, within the cup, which is known as the trigger, and it has a lip which extends through a slot cut in the periphery of the cup. Mounted directly beneath the coupling is a notched bar, which is so placed that the notch is in line with the slot in the cup so that the trigger drops down under the action of gravity and holds the cup from rotating. This condition is shown in the ring, C, Fig. 319. On the outside of the trigger ring there is a cam which engages a corresponding cam cut in the driving tube. After the lip on the trigger has become engaged with the notch in the notched bar, as shown in C, the tube A continues to rotate and causes the spring, which is held between a driving pin, E, attached to the tube A and a block fixed to the cup B to be compressed. At a predetermined point, the cam on the trigger ring engages the cam on the tube A and lifts the trigger high enough **for the lip to**

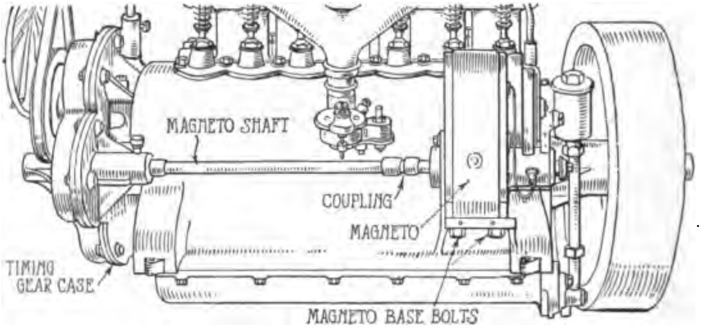


Fig. 316—*Magneto driven from timing gears* disengage the notched bar, and the compression of the spring spins the cup around at a momentarily high speed in a clockwise direction. This momentary high speed gives a very hot spark and may be equivalent in intensity to one obtained under ordinary conditions at an engine speed of several hundred revolutions per minute.

At slow speeds the cup is caught again and again as the driving member of the coupling causes it to rotate, but when the speed has attained a certain value, the trigger ring by its own weight becomes a ring governor and the centrifugal force keeps the lip from dropping down the slot in the tube B. A small lug on the inside of the trigger ring in line with the lip and on the same side engages a notch in the tube A and thus provides a positive drive so long as the speed is maintained.

Sumpter Impulse Starter

An impulse starter as made by the Sumpter Electrical Co. is shown in Fig. 320. It consists of a notched member, A, fastened to the end of the armature shaft, and a driving member, B, which has two small extensions on its outer surface directly opposite each other. These two members are connected by springs as shown in Fig. 321, which also shows method of replacing springs. A small pin extends from the surface of the member B into the opening between the ends of the two springs. The short spring

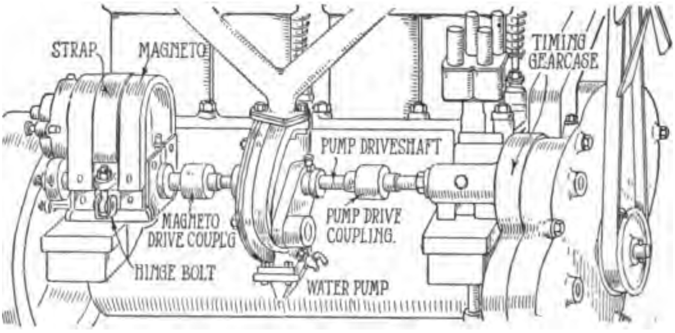


Fig. 317—*Magneto driven by extension of pump shaft* acts as a bumper spring and tends to absorb the shock of the longer spring when the armature of the magneto is driven forward suddenly. A pawl, C, is mounted in such a position that it will engage the notches in the outer surface of the driven member, A, as this member tends to rotate, provided the end of the pawl is

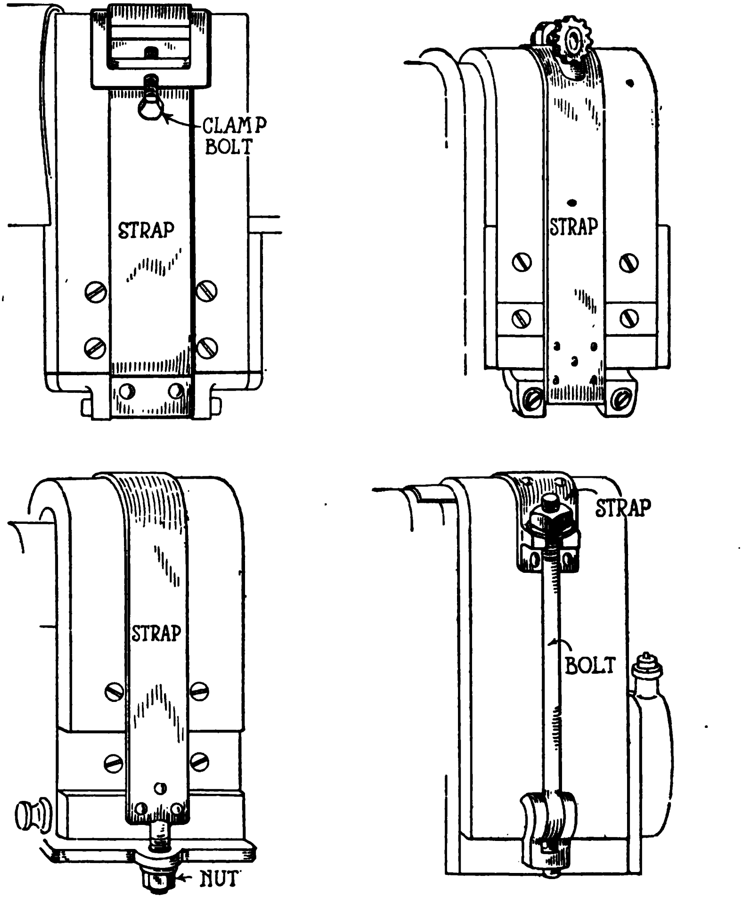


Fig. 318—Typical methods of holding magnetos in place

turned so that the action of the spring tends to press it down on the outer surface of the member A. Assuming the pawl is engaged in one of the notches in the member A and that the member B is rotating, then the long spring will be compressed. As the member B rotates, one of the extensions will move under the end of the pawl and raise it out of the notch in the member A and allow the member A to rotate momentarily at high speed until it automatically restores the pawl to the operating position when the speed drops below a certain value.

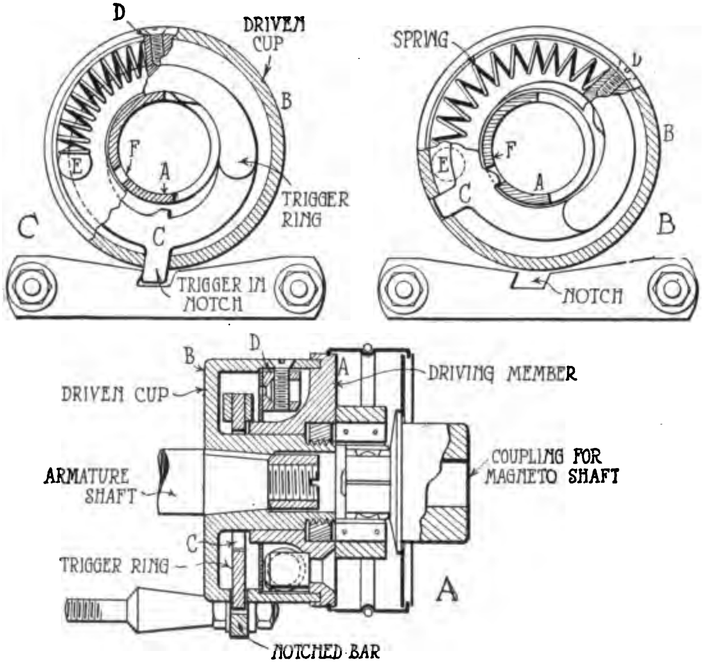


Fig. 319—*Eisemann impulse starter, consisting of a notched member and a driving member*

The shape of the end of the pawl and the slots in the surface of the member A is such that the pawl is thrown out with such force when the speed has reached a certain value that it becomes entirely inoperative as shown in the figure. It is then necessary to press the pawl down by hand. This restoring operation, however, is not necessary in all models made by the Sumpter Electrical Co., as some are provided with a centrifugal attachment which is again caught by the pawl and the operation repeated.

Ford Magneto

The construction of the Ford magneto is radically different from other types, although the fundamental principle upon which it operates is in itself not new. Instead of using two or three horseshoe magnets as in the ordinary magneto the Ford has sixteen permanent magnets arranged in a radial manner with their poles pointing outward and all bolted to one surface of the flywheel as shown in Fig. 322. Mounted directly in front of these magnets and separated by a very small air gap are sixteen coils of copper ribbon. These sixteen coils are mounted on a metal spider which is rigidly attached to the crankcase of the engine, as shown in Fig. 323. The spider and the coils remain stationary, and the magnets are moved past the coils as the flywheel of the engine is rotated, which results in an electrical pressure being induced in the coil windings. These coils all are connected in series and in such a manner that the pressure induced in them is additive so far as the external circuit is concerned. One terminal of the circuit is grounded and the other terminal connected to a metal ring. A brush is mounted in the upper part of the flywheel case and in-

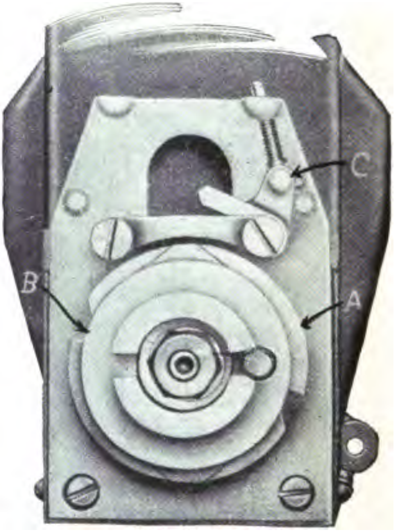


Fig. 320 — *Impulse starter made by the Sumpter Electrical Co.*

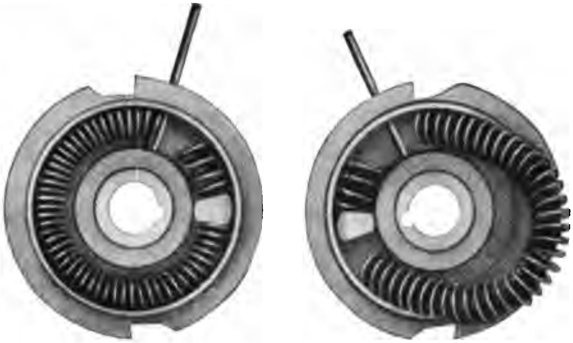


Fig. 321—How the driving and notched members of the Sumpter are connected

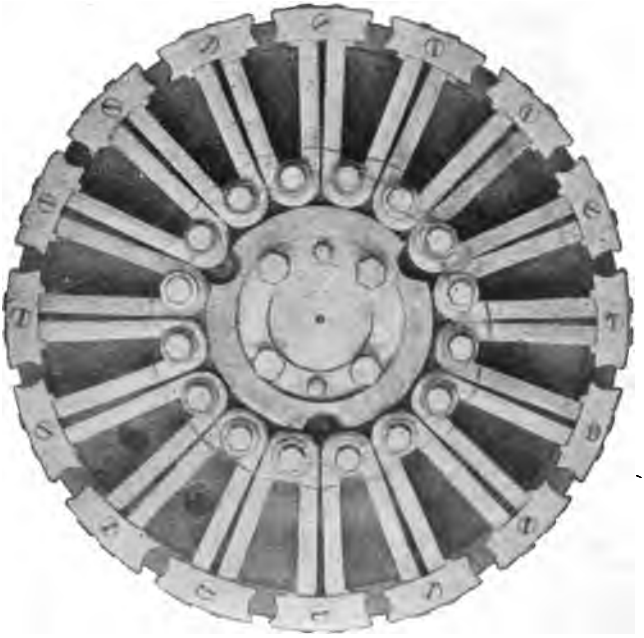


Fig. 322—Permanent magnets of Ford magneto

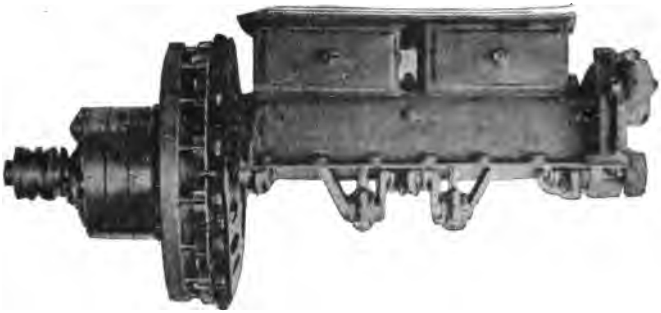


Fig. 323—Ford magneto installed on engine

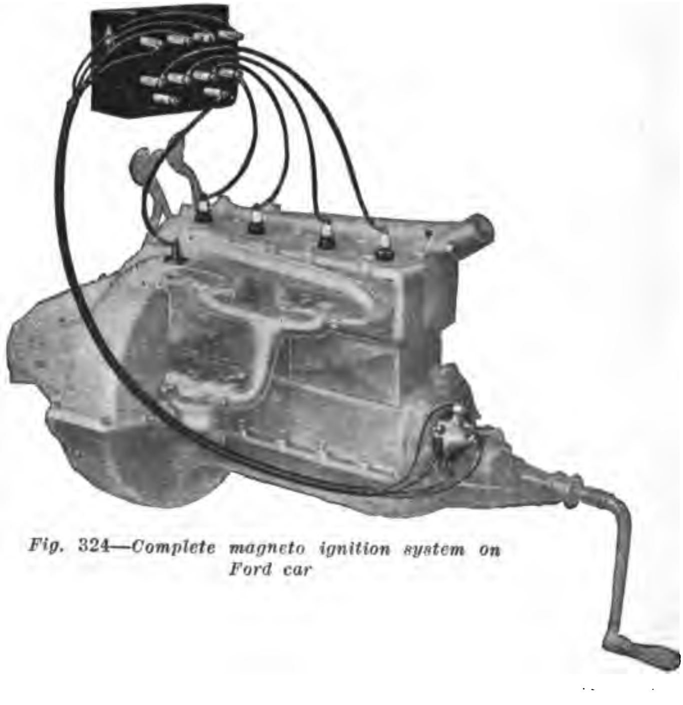


Fig. 324—Complete magneto ignition system on Ford car

sulated from it, which makes continuous contact with the just mentioned ring. The mounting of this brush is provided with a binding post outside of the flywheel case, which forms one terminal of the magneto winding.

The complete Ford magneto ignition system is shown in Fig. 324. The four-unit coil is shown in the upper part of the figure. An inspection of the figure will show the following connections: A wire leading from the collector brush on the magneto to one of the lower binding posts on the back of the coil; four primary wires leading from four binding posts on the back of the coil to four binding posts on the low-tension timer, and four high-tension cables leading from four binding posts on the back of the coil to the four spark plugs. The timer is mounted on the forward end of the engine and driven from the camshaft gears.

The wiring diagram of the Ford ignition system is shown in Fig. 325. The switch located in the lead running from the magneto to the coil may be so arranged that a primary, or storage, battery may be used in place of the magneto in supplying current for ignition purposes. The timer is shown directly above the generator and the firing order of the different cylinders may be determined by tracing out the low-tension wires to the different primary windings and the corresponding high-tension wires to the different coils.

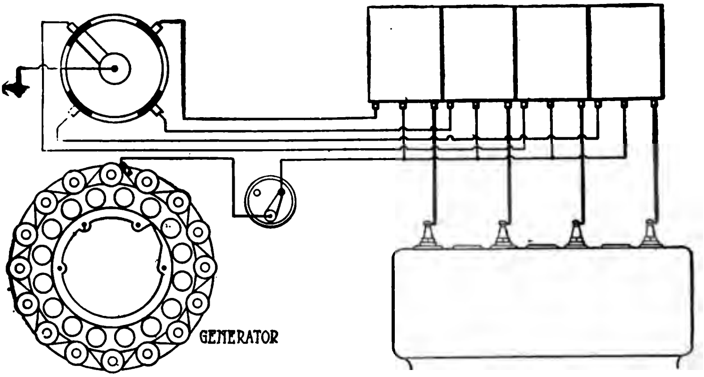


Fig. 325—Wiring diagram of Ford ignition system

The current such a magneto supplies is, of course, an alternating current, and it completes sixteen complete cycles for each revolution of the flywheel of the engine. It may happen that the timer contacts are closed when the electrical pressure in the magneto winding is zero or very low in value, and if such is the case sufficient current will not be produced in the primary winding of the induction coil to cause its armature to vibrate and produce a spark. This results in the spark not being uniformly advanced or retarded as the timer is moved by means of the spark lever, which doubtless accounts for the fact that the engine often will be found to operate much better with the timer advanced but a part of its maximum travel instead of the total amount possible as in the case of the ordinary magneto and battery systems.

Spark Timing

The power output of a gasoline engine depends on the mean effective pressure developed in the engine cylinders. The value of the mean effective pressure is effected by three principal factors: First, the compression to which the gaseous mixture in the cylinders is compressed by the piston on its upward, or compression, stroke just before firing; second, the exact time of the ignition spark in relation to the position of the piston, and third, the length of the stroke of the engine cylinder. It is readily seen that it is the second factor of the above three which concerns the problem of ignition. To obtain the best results, the ignition of the gaseous mixture must take place at the time of maximum compression, which corresponds to the uppermost position of the piston.

Since there is both a mechanical and electrical lag in the results obtained from the ignition spark, it is readily seen that the same setting of the spark which will give maximum efficiency at say 500 r.p.m. will be quite a bit too late for a speed of 1000 r.p.m., and the spark would not then take place until the piston had started on its downward stroke and the pressure had dropped considerably, causing a very noticeable loss in power. Likewise, if an attempt be made to run the engine at a slow speed with the spark accruing at a time which gives the best results for high speed, there will be a marked loss in power, due to the fact that the explosion of the gaseous mixture takes place against the rising piston. This condition of affairs is indicated by a decided hammering sound in the engine cylinders. In the majority of ignition systems means are provided for advancing and retarding the time of the spark in relation to the position of the piston. This change in spark position in the great majority of systems is accomplished by moving a lever, called the spark lever, which is within easy reach of the operator, while in some it is accomplished by an automatic device whose operation usually depends on the centrifugal action on one or more weights. In some cases the automatic and manual means are combined, and in a few no means of changing the position of the spark is provided at all.

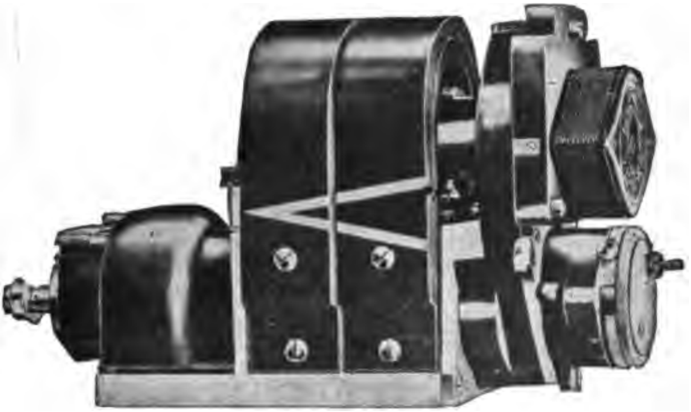


Fig. 326—Eisemann device for advancing and retarding spark automatically

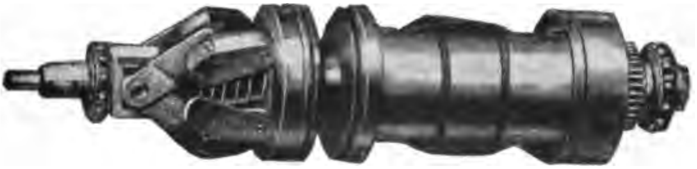


Fig. 327—Eisemann high-tension magneto and automatic timing device complete

A centrifugal device for advancing and retarding the spark automatically as conditions may require is shown in Fig. 326. The complete magneto with the automatic timing device is shown in Fig. 327.

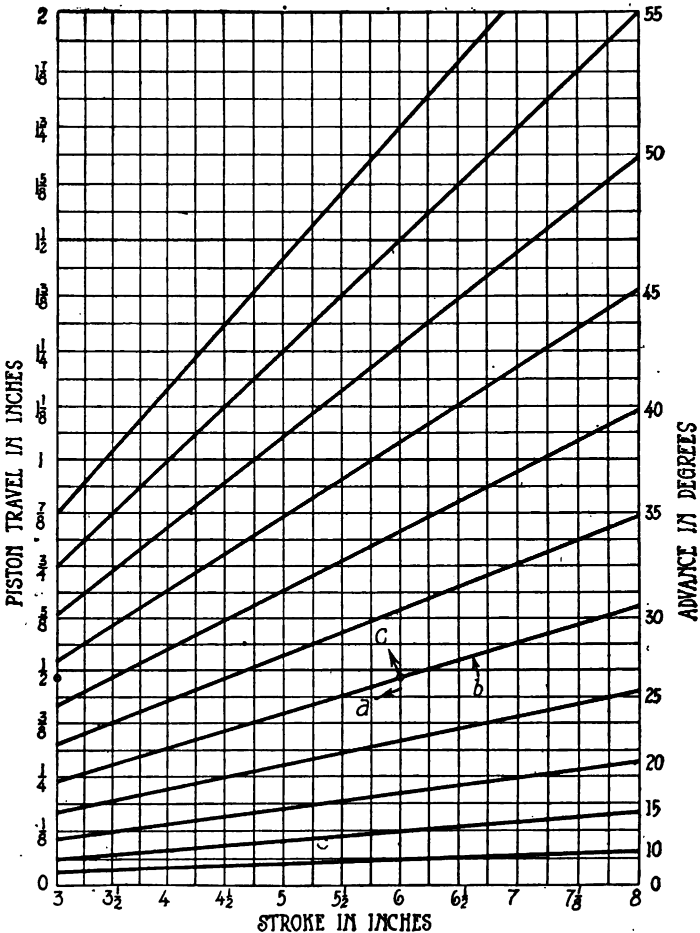


Fig. 328—Chart for determining relation between spark advance and piston travel

A convenient chart for determining the relation between the spark advanced in degrees for different piston strokes in inches with engines having strokes varying from 3 to 8 inches is shown in Fig. 328. The chart may be used as follows: Assuming the spark is to be advanced 30 degrees in an engine having a 6-inch stroke, to find the amount the piston should travel trace the vertical line corresponding to the stroke in inches until it intersects the sloping line corresponding to the 30-degree line, and then follow the horizontal line to the left, which brings you out just a little below the ½-inch division. The piston then would have to travel a little more than ½ inch below the uppermost position and moving upward in order that the spark have a 30-degree lead.

CHAPTER XXIII

Battery-Generator Ignition

THE fundamental principle of all battery ignition systems, together with the main parts, is shown diagrammatically in Fig. 329. The electrical circuits for convenience may be spoken of as the low- and high-tension circuits, or the primary and secondary circuits respectively. The primary circuit consists of the following main parts, starting at the positive terminal of the storage battery and tracing along the circuit in the direction of the curves: The low-tension, or primary, winding of the induction

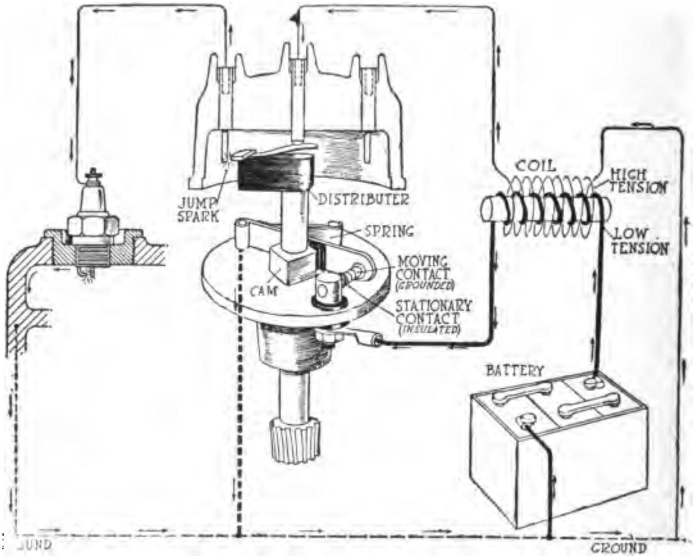


Fig. 329—*Diagram illustrating principle of all types of battery ignition systems* coil through the stationary and movable interrupter contacts and back to the negative or grounded terminal of the battery. The high-tension circuit consists of the following parts: Starting with the ground connection, you pass through the high-tension, or secondary, winding of the induction coil to the center contact of the distributor head, through the distributor brush to the various contact points, depending upon the position of the distributor brush, to the spark plugs through the spark gap and to ground. In some systems there is a small gap between the distributor brush and the various contact points, and it is necessary that this gap be bridged, in addition to the gap at the spark plugs, whenever a spark occurs in the engine cylinders. In the majority of systems, however, no such gap is provided, and the end of the distributor brush makes actual contact with the various points which are electrically connected to the spark plugs.

Open- and Closed-Circuit

All battery ignition systems may be considered as belonging to either of two types of systems, called the open- and closed-circuit types respectively. The distinction between these two types may be understood readily by reference to the diagrammatic representation of each as shown in Figs. 330 and 331. In the closed-circuit system the ignition contacts normally are closed and the operation of the cam opens these contacts. The contacts are shown in the open position in Fig. 330. In the open-circuit system the contact points normally are open and the operation of the cam closes these contacts directly or through the intermediate action of a system of weights or levers. The operation of the open-circuit system, as shown diagrammatically in Fig. 331, may be considered as taking place as follows: The spring is raised by the cam and suddenly lowered or released and its end strikes the end of the spring carrying the movable contact and thus causes the two contacts to be momentarily in contact with each other. In either system a high electrical pressure will be induced in the high-tension, or secondary, winding of the induction coil where the current in the primary winding is interrupted, provided the primary circuit has been closed long enough to allow the primary current to build up in value so as to produce the necessary number of lines of magnetic force through the secondary winding.

Current Lag

The current in the primary winding does not build up in value to its maximum value instantly, but an appreciable time is required. The rapidity with which the current increases in value after the circuit is closed depends on the relation between the resistance and the induction of the circuit. The higher the induction and the less the resistance, the greater the time required for the current to reach a certain value, or, in other words, the slower the current builds up in value. The value of the inductance of the circuit in henries divided by the resistance of the circuit in ohms gives the numerical value of what is called the time constant of the circuit, which is the time required for the current to rise to .63 of its maximum value. For example, if a circuit had a resistance of 2 ohms and an inductance of .0005 henry its time constant would be equal to .00025. If a pressure of 6 volts be impressed on this circuit the maximum current would be equal to six divided by two, or 3 amperes, and the current would reach a value of 1.99 amperes in .00025 second after the circuit was closed.

Time Constant

The time constant of an ignition circuit, of course, can be changed in value, but it never can be equal to zero, as it is impossible to reduce the inductance to zero. The intensity of the spark produced will vary its value as the value of the total number of lines of force threading the secondary circuit and cutting the secondary winding when the primary circuit is broken varies in value. Hence, it is desirable to have the primary current reach as high a value as possible before breaking the primary circuit. In the closed-circuit system the primary circuit is opened a less number of times for low engine speeds than it is for high engine speeds, and the duration in time of each interval that the circuit is closed is greater.

The relation between the time interval that the circuit is closed and the time interval that the circuit is open supposedly is the same regardless of the engine speed. Since the time intervals that the circuit actually is closed at any one time decreases as the speed of the engine increases, it readily is seen that the speed of the engine finally may reach such a value that the primary circuit may not be closed long enough to allow the primary current to rise to the necessary value to reduce the required intensity of spark. As a result of this condition the current actually taken by the primary circuit of a closed-circuit battery ignition system, as indicated on a suitable ammeter, decreases in value as the speed of the engine increases. The relation between current and engine speed for a four- and six-cylinder engine operated by a closed-circuit Atwater Kent ignition system is shown by the full lines in Fig. 332.

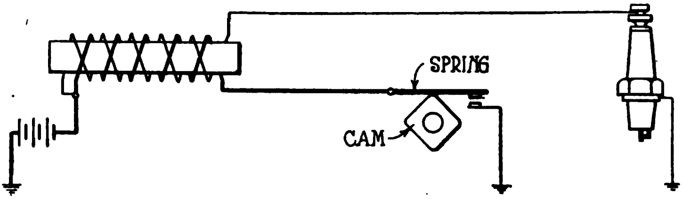


Fig. 330—*Diagram of closed-circuit system of ignition, with contacts in open position*

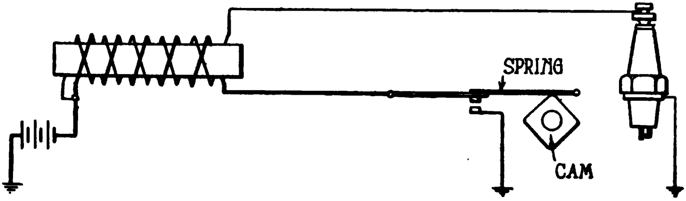


Fig. 331—*Diagram of open-circuit system of ignition, with contacts in open position*

In the open-circuit type of ignition the primary circuit is closed for the same interval of time, regardless of the engine speed, and the primary current always builds up to the same actual value each time the circuit is closed. This results in the electrical pressure that is induced in the secondary winding and the spark being practically the same for all engine speeds. The current taken by such a system will increase in value as the speed of the engine increases. The relation between current and engine speed for a four- and six-cylinder engine operated by an open-circuit Atwater Kent ignition system is shown by the dotted lines in Fig. 332.

The behavior of the various ignition devices may be investigated by a device called an oscillograph and all well-equipped experimental laboratories are equipped with one. By means of the oscillograph the variation in primary and secondary current with respect to time readily may be investigated. The results of an investigation of both closed- and open-circuit types of ignition by the oscillograph are shown in Fig. 333. The two upper horizontal rows of curves are for an open-circuit type of system in which the primary circuit is closed for the same interval of time each time the circuit is closed. The upper row of curves indicates the same maximum value of secondary current, or voltage, for all engine speeds.

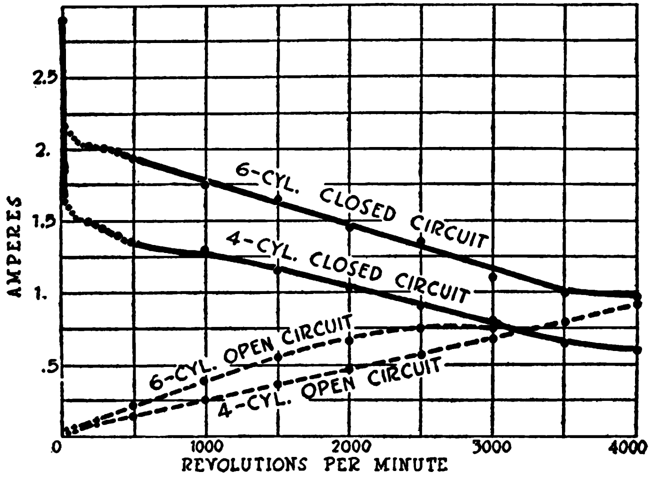


Fig. 332—*Comparative current consumption for open- and closed-circuit ignition systems*

The two lower horizontal rows of curves are for a closed-circuit type of system in which the primary circuit is closed for different intervals of times each time it is closed and the engine speed is different. For the high engine speeds the primary current is not closed long enough for the primary current to reach its maximum value, and hence the secondary current, or voltage, is not as high as it is at low engine speeds.

The operation of the open-circuit type of interrupter for the K3 type of battery ignition system manufactured by the Atwater Kent Co. is in brief as follows: Four different positions of the interrupter in one of its cycles of operation are shown in Fig. 334. The ratchet A has as many notches as there are cylinders to be fired. The ratchet is mounted on the central vertical shaft of the device, which also carries a distributor and in this combined form is known as a unisparker. On four-cycle engines it is driven at half crankshaft speed, on two-cycle engines at crankshaft speed.

The ratchet A engages the lifter B, and as A rotates its teeth or notches successively tend to draw B with them against the tension of the spring C. In doing so the head of B strikes the swinging lever, or hammer, D, whose motion in both directions is limited as shown, and the hammer communicates the blow to the contact spring E, bringing the contact points together momentarily. E is a compound spring, the straight member of which carries the movable contact, while the stationary contact F is mounted opposite it. The second member of this compound spring is curved at its end to engage the straight member. Ordinarily the straight spring blade is held under the tension of the curved blade and the contact points are held apart. When the curved blade is struck by the hammer D the points come into contact with each other. The curved blade, however, is thrown over farther by

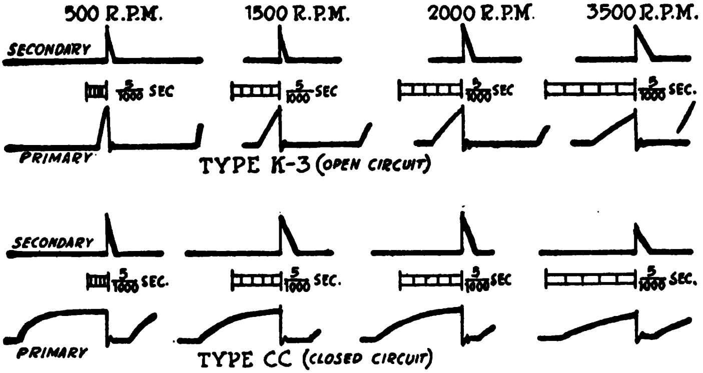


Fig. 333—Oscillograms, showing variation in primary and secondary currents for ignition systems

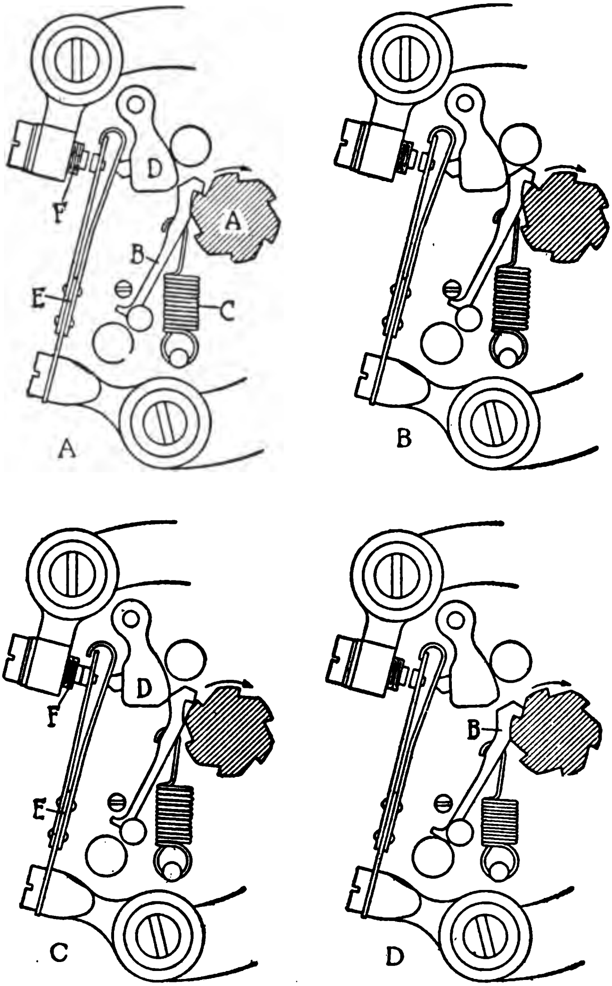


Fig. 334—Diagrams showing operation of Atwater-Kent interrupter

the impact and its hook leaves the straight blade. Upon reaching the limit of its movement, it flies back and strikes the end of the straight blade a blow, causing a very sharp break of the circuit. This movement is so extremely rapid that it cannot be detected by the unaided eye, so that its working cannot be tested simply by watching the operation of the contacts as in the case of a magneto interrupter. B, C and D of Fig. 334 show the successive movements of the parts during a single cycle. In A a notch of the ratchet has engaged B and is drawing it against the tension of the spring C. In the second sketch, B, the hook is just being released; in C the lifter is riding back over the rounded portion of the ratchet and is striking the hammer D, which in turn pushes E for a brief instant against F. The return of B to the position shown in sketch D is so rapid that the eye cannot follow the movement of the parts D and E, which to all appearances remain stationary.

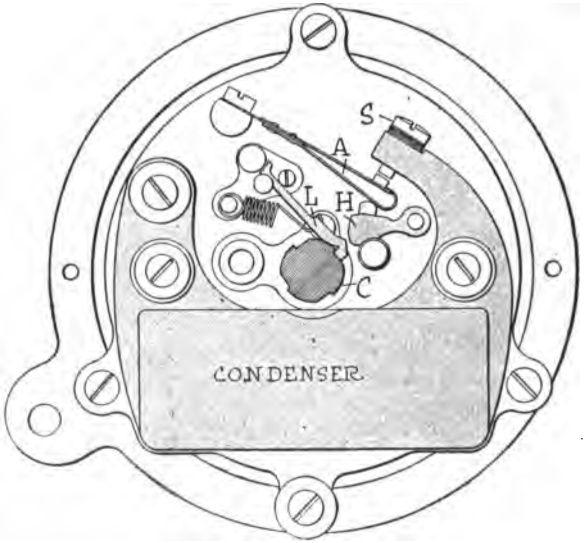


Fig. 335—Location of condenser in Atwater-Kent open-circuit breaker

Adjustment of the contact points is made by removing one of the three washers from under the head of the contact screw F, and the gap should be .010 to .012 inch, never exceeding the latter.

Where more accurate means of determining this distance are not available, it may be gaged with a piece of manila wrapping paper, which should be perfectly smooth. With the aid of a micrometer, a sheet of paper of the proper thickness can be selected. The contact points are of tungsten, and as the moving parts are all of glass-hard steel very accurately machined, the wear is negligible, so that adjustment is not required oftener than once in perhaps 10,000 miles and a replacement of contact points after running perhaps 50,000 miles.

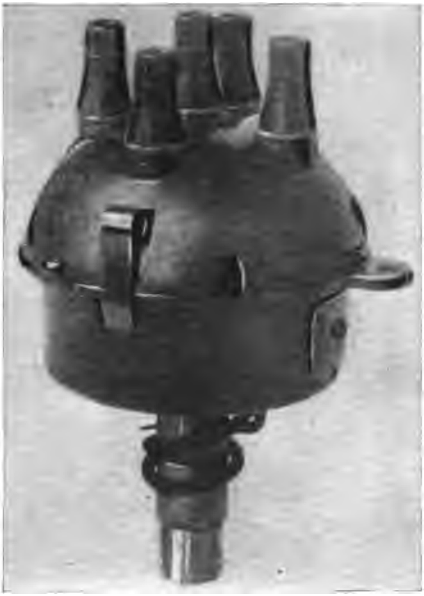


Fig. 336—*Complete Atwater-Kent timer-distributor unit for K3 systems*

In the latest models of this K3 type of ignition system, the condenser is located within the timer-distributor unit and in very close proximity to the contacts. The location of the condenser is shown in Fig. 335, and the complete timer-distributer unit is shown in Fig. 336. This arrangement permits a reduction in the size of the condenser and at the same time increases its effectiveness. An automatic spark-advance mechanism is provided, which operates by centrifugal force, and this automatically advances the time at which the circuit is made and broken to compensate for the increase in speed.

Atwater Kent System

The Atwater Kent closed-circuit battery ignition system is styled model CC. It is quite different from anything else of its kind and is marked by great simplicity, light weight of parts, very few moving parts, an absence of any bearings in the contact-carrying arm and compactness.

The base on which the unit is built up is an iron casting on which the various parts are screwed rigidly. The whole device, consisting of timer, distributor and coil and mounted on a magneto type of base, is shown in Fig. 337. The breaker is shown in Fig. 338. The contact arm is an exceptionally light steel stamping tipped with fiber where it touches the cam. The arm is riveted to a short length of a spring steel, D, which in turn is riveted to the block L. The distributer cover is Bakelite, with the terminals molded in place. There is no wiping contact in the distributor, the air gap between the nickel alloy distributor blade and the terminals being .015 to .020 inch. The specially shaped cam has been adopted only after long experimentation, during the course

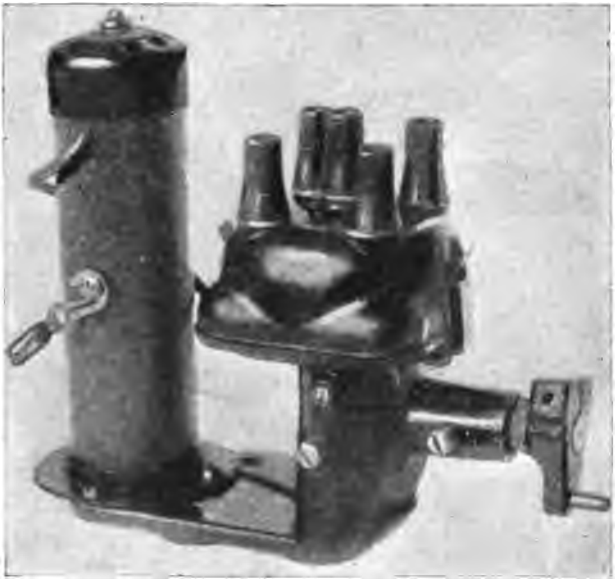


Fig. 337—Atwater Kent model CC battery ignition system mounted on magneto base

of which it developed that even the slightest variation in the radius of the curved portions between the flats exerted a powerful influence on the character of the spark.

Rotation of cam brings its corners in contact with the fiber tip T of the contact arm A, thus separating the contacts and breaking the circuit. The contacts are together for a considerable period, thus permitting the coil to be saturated thoroughly.

The contacts are of tungsten, the one in the arm being forced in place. There is but a single adjustment. To alter the size of the gap between the contacts the screw S is loosened and the arm B moved the required distance. The light weight of the contact arm is an important factor in the operation of the breaker. In addition to reducing wear to a minimum, it eliminates harmonic vibration and operates to intensify the spark at high speeds.

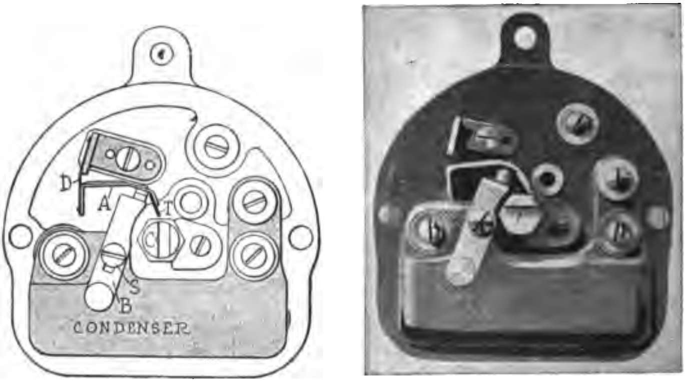


Fig. 338—Model CC Atwater Kent breaker, the drawing showing the operation of breaker

The condenser is located as close to the contact as possible to increase its efficiency. On account of its proximity to the contacts, this condenser needs to be only about a sixth the size that would be required were it located in the coil container as commonly done. Furthermore, the condenser is much more accessible in this location, though it is rarely necessary to touch it at all.

The current consumption of this system is comparatively low at low speeds and does not fall off as fast at high speeds as might be expected. Throughout the entire range the consumption is sufficient to insure a hot spark.

Bosch System

The Bosch battery ignition system consists of a combination breaker and distributor and a combined switch and coil, the latter being mounted on the dash so that the switch is within easy reach of the driver. The complete system is shown in Fig. 339. The breaker mechanism is shown in Fig. 340. Rotation of the cam C causes the arm carrying the movable contact to move in such a manner as to open the circuit. The contacts are held closed by a spring, except when the projections on the cam are under the fiber block attached to the arm.

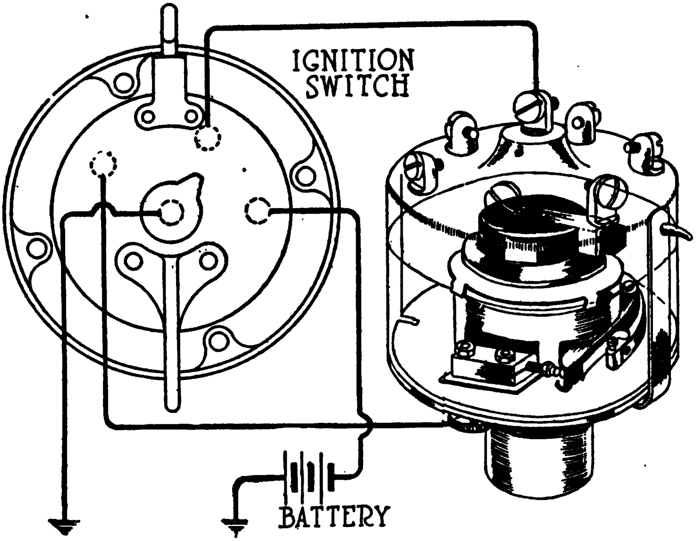


Fig. 339—Complete Bosch battery ignition system, including combination breaker and distributor and combined switch and coil

The distributer mechanism is mounted directly over the breaker and is quite simple. It consists of the customary cover, with the terminals molded in place. A radial arm carries a carbon brush, which makes a wiping contact with the various terminals for the wires leading to the different spark plugs. A cross-section of the combined breaker and distributer is shown in Fig. 341, and an exterior view is shown in Fig. 342.

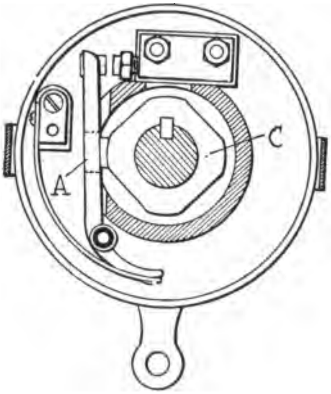


Fig. 340—*Breaker mechanism of Bosch system*

The switch is so arranged that a magneto may be used, and the engine will run on the magneto with the switch in one position and on the battery with the switch in the other position. A vibrator attachment is incorporated with the switch to facilitate starting the engine when it is cold or the carbureter is out of adjustment. This vibrator mechanism is controlled by a pointed button in the center of the switch plug. Under normal starting conditions momentary pressure on the button will produce a single spark at the plug

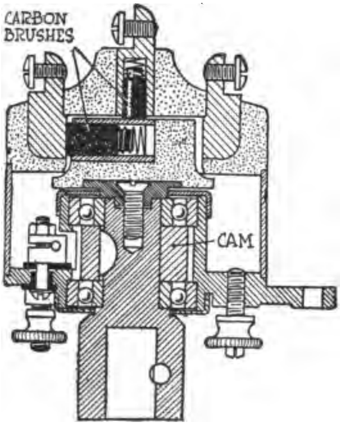


Fig. 341—*Cross-section of Bosch combined breaker and distributor*

Fig. 342—*Exterior view of Bosch combined breaker and distributor* if the distributer brush is making contact with one of the distributer terminals. Turning the button to the right and depressing it makes the necessary connection to provide a stream of sparks at the different plugs, depending on the position of the distributor arm. If desired, the button can be locked in this position until the motor has started.

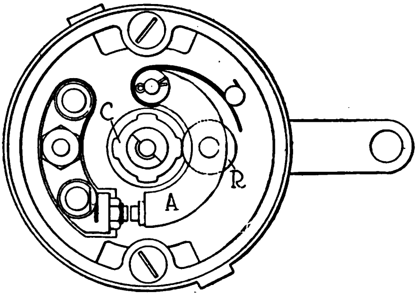


Fig. 344—*Breaker mechanism of Connecticut ignition system*

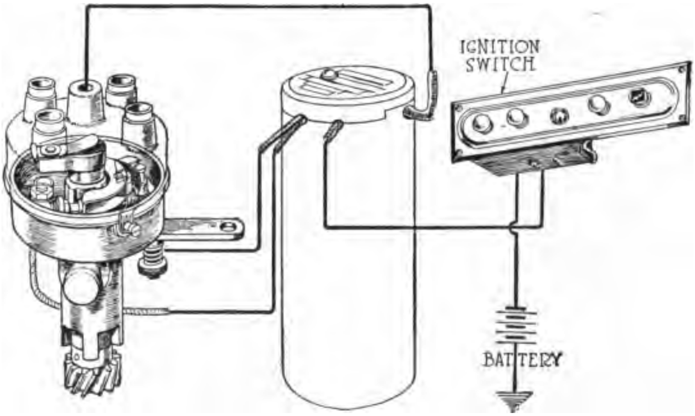


Fig. 343—*Complete Connecticut battery ignition system, which operates on the closed-circuit principle*

There is only one adjustment, and this is for the gap at the contacts. With the fiber block attached to the movable arm resting on the top of one of the projections on the cam, the contacts should be separated about .01 inch. To alter the adjustment the lock unit holding the stationary contact must be released first, and then carefully secured after the adjustment is made.

Connecticut System

The Connecticut system operates on the closed-circuit principle and is made for four-, six- and eight-cylinder engines. The complete system is shown in Fig. 343. The breaker mechanism is shown in Fig. 344. As the cam C rotates the high parts come into contact with the roller R in the arm A, and thus separates the contacts. The arm A is returned to its normal position by a spring. The breaker mechanism is mounted on a plate which rests in the casing and is held in place by a spring ring and solid ring, the latter being held by two screws. The advance lever engages a stud on the breaker plate, the whole plate being advanced around the shaft to advance the time of ignition. The various parts of the combined breaker and distributor are shown in Fig. 345. The complete device with the distributor cap removed is shown in Fig. 346, and complete with the cap in position in Fig. 347. The operation of the advance lever in bringing about a proper timing is shown in Fig. 348.

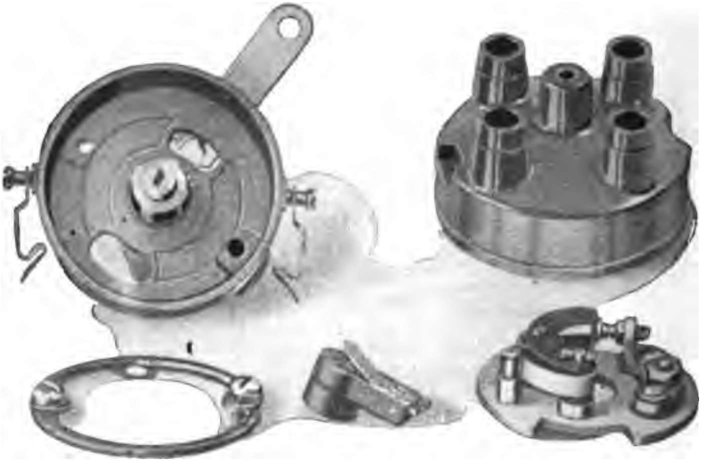


Fig. 345—*Various parts of combined breaker and distributor of Connecticut system*

A very ingenious device is provided to prevent the possibility of the battery being exhausted, due to the ignition switch being left closed and the engine stopped. This device is a small thermostat connected in series with the primary circuit, which controls a mechanism similar to that in an ordinary door bell. If the engine happens to be stopped with the ignition switch closed, the primary current in passing through the thermostat heats it, thereby bending it and closing a circuit through a buzzer mechanism. This in turn automatically opens the switch. The action of the thermostat can be set for anything from 30 seconds to 4 minutes, the normal setting being about three-quarters of a minute.

In the latest designs a spark gap has been provided between the distributor brush and the contacts instead of a wide contact. To prevent oxidization the cover is ventilated through two tiny holes so as not to decrease the weatherproof properties of the instrument. Rotation of the distributor arm acts to keep the housing well ventilated. The wiring to the coil is so arranged through the use of a hexagonal terminal that it is impossible to put a wire on the wrong connection.

***Fig.* 346—*Connecticut combined breaker and distributor with cap removed, above, and complete, right, Fig.* 347**

Pittsfield System

The Pittsfield system operates on the open-circuit principle and is entirely different from any of the other open-circuit systems. The principal point of difference is that contacts are brought together mechanically and separated mechanically, neither operation depending on the operation of a spring. The breaker, distributor and coil all are a single unit and the systems are supplied for four-, six-, eight- and twelve-cylinder engines. The inter-relation of the different parts is shown in Fig. 349. The breaker mechanism is shown in Fig. 350.

Normally the contacts are separated. Rotation of the cam C presses the arm carrying the lever contact up, thus bringing the contacts together mechanically with a firm pressure and so holding them. Further rotation of the cam brings it in contact with the fiber member F on the end of the arm carrying the second contact, thus positively breaking the circuit. Still further rotation of the cam fills both arms, so that the contacts remain separated until again brought together by the rotation of the cam. The only adjustment is that which has to do with the opening of the contacts, and these are easily accessible from outside the casing. Removal of the distributor cover and coil exposes the distributor mechanism, and after the key holding the camshaft has been withdrawn the whole shaft

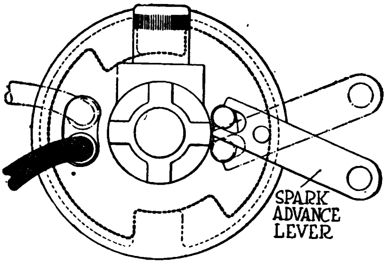


Fig. 348—*Operation of spark advance lever on Connecticut*

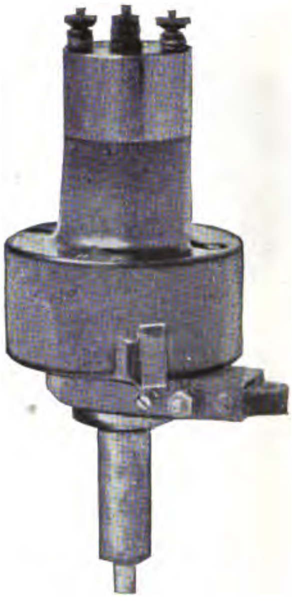
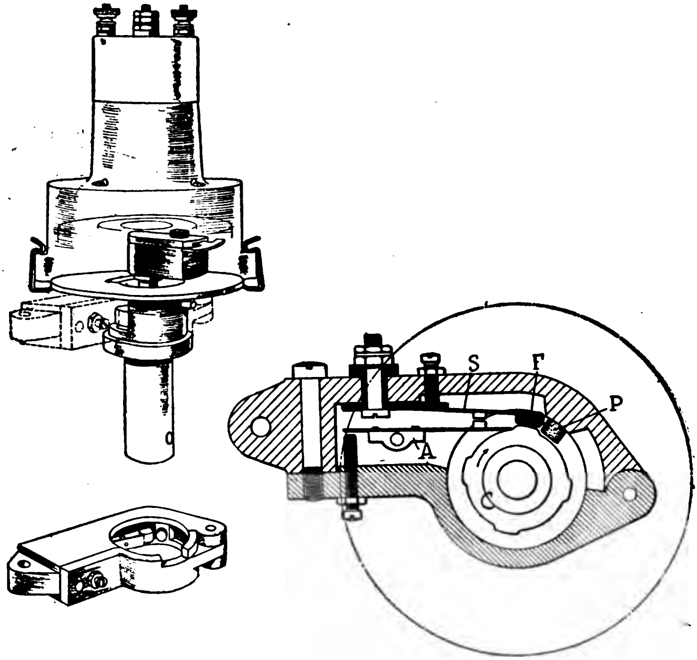


Fig. 351—*Pittsfield battery ignition system complete* can be lifted out in case this should be necessary. The complete device is shown in Fig. 351.

Remy System

The Remy system operates on the closed-circuit principle, and it is distinguished by the fact that it has but two moving parts—the cam and the breaker arm. The complete system is shown in Fig. 352. The breaker mechanism is shown in Fig. 353. The rotation of the cam C brings its corners in contact with a fiber plug which is riveted to the breaker arm. The arm thus is lifted, separating the contacts. Only hand advance of the breaker mechanism is provided.



Figs. 349 *and* 350—*Interrelation of parts in Pittsfield system, left, and breaker mechanism of Pittsfield*

Another particular feature of the Remy unit is that the whole mechanism is stationary. Advancing or retarding the spark does not move any of the wiring. This is accomplished by mounting the breaker mechanism on a plate. This plate is attached to the advance lever and is moved with it, thus rotating the breaker mechanism partly around the cam.

The distributor mechanism consists of the usual Bakelite oven, with terminals molded in place. There are no wiping contacts, the spark jumping from the radial distributor arm to the terminals and thus eliminating wear.

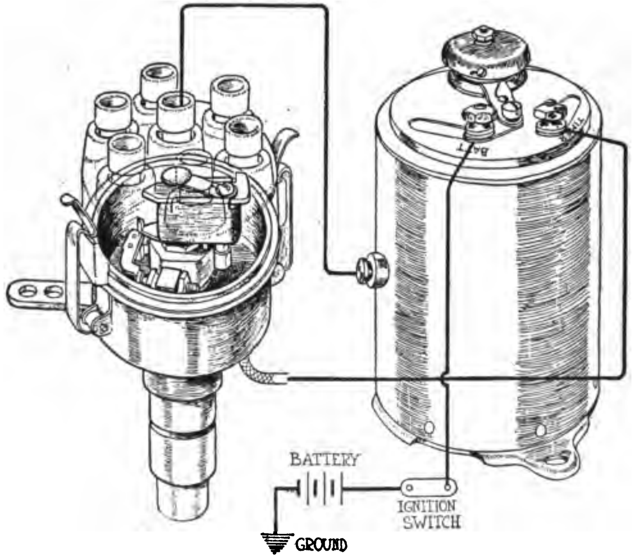
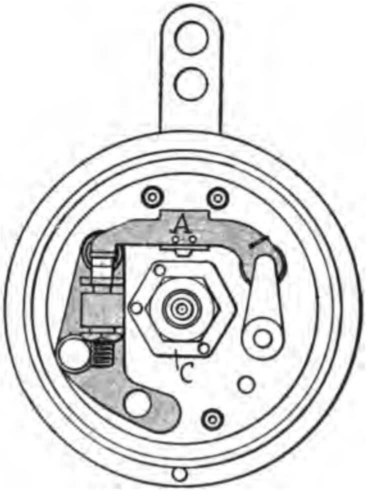


Fig. 352—Complete Remy battery ignition system, which operates on the closed-circuit principle

A small resistance coil is located on top of the ignition coil and is connected in series with the primary winding. The object of this resistance is to protect the winding and at the same time prevent an excessive drain on the battery should the engine be left idle for any length of time with the ignition switch closed. The protection is provided by the resistance of the coil increasing very rapidly when the current through it exceeds a certain value or, what amounts to the same thing, when its temperature exceeds a certain value, thus causing the resistance to increase very rapidly.

The makers claim that the contact points, which are iridium-platinum, or tungsten, should not require attention more than twice a season. These contacts should be dressed with a fine flat file so that surfaces will be smooth and parallel, and they should be adjusted with the wrench provided by the makers so that the maximum opening is from .020 to .025 inch or the thickness of the gage piece riveted to the wrench.



Figs. 353 *and* 354—*Breaker mechanism of Remy, above, and combined breaker and distributor of Remy battery ignition system*

If the engine misses when running idle or at light loads the gaps at the plugs should be wider. If the engine misses when running at high speeds or when pulling hard the gaps should be narrower.

The oiler on the shaft should be kept filled with medium cup grease and screwed down two or three turns occasionally. On some of the devices a wick oiler is used, and in such cases pure vaseline should be used instead of the cup grease. The complete combined breaker and distributor of the Remy company is shown in Fig. 354.

Rhoades System

The Rhoades system operates on the open-circuit principle, and in its new form it has been amplified considerably, though the principle remains unaltered. The couple system is shown in Fig. 355 and consists of the combined breaker and distributor unit and a combined coil and switch unit.

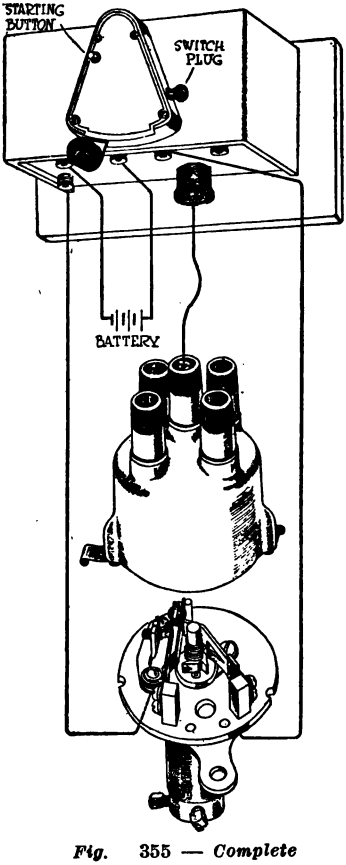


Fig. 355 — Complete Rhoades battery ignition system, which is compact and simple

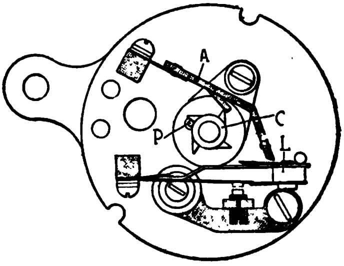


Fig. 356—Breaker mechanism of Rhoades system

The breaker portion of the breaker distributor unit is shown, as seen from the top, in Fig. 356. The cam C is mounted loosely on the shaft and rotates with it by contact with the pin P, which is rigid, so far as rotation is concerned, with respect to the shaft. As the cam C rotates it presses the arm A outward, and this arm in plunging back, hits against the lever L, thus forcing the contact together momentarily.

If the cam is rotated in the reverse direction it simply rides over the pin and does not bring the contact together. The contacts, it must be remembered, are brought into contact solely by the momentum of the arm A, and for this reason the duration of contact remains the same regardless of engine speed. The characteristics of the spark then should be the same for all engine speeds.

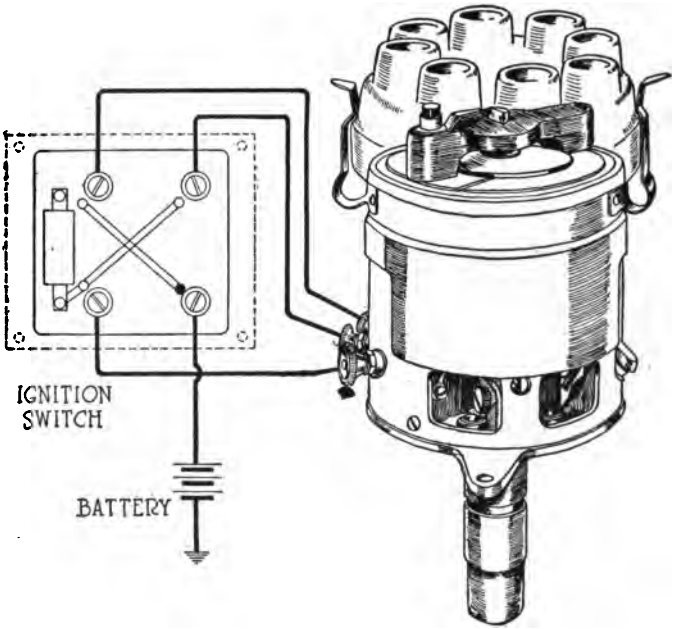


Fig. 357—*Complete Westinghouse battery ignition system*

The distributor is the usual Bakelite construction with brass terminals molded in place. The distributor arm is keyed to the shaft with a set screw, and the construction is such that it cannot be assembled improperly. The distributor arm does not make contact with the terminals, but the spark jumps a small air gap.

There is only one adjustment to make on the device and that is to regulate the distance between the contacts. They should be about $\frac{1}{32}$ in. apart at all times. Since the action of the device is entirely too rapid to be seen, care must be taken that each of the parts is functioning properly.

There is a single oil cup on the distributor and this should receive a drop of light machine oil twice a week for continuous driving. From time to time the cover should be removed, and if the cam appears dry, a very small quantity of thin oil may be put on it. Under no circumstances should the tension of the various springs be altered at all.

Westinghouse

The battery ignition system manufactured by the Westinghouse Electric & Mfg. Co. operates on the closed-circuit principle. The complete system, breaker, distributor and coil, is self-contained as shown in Fig. 357. The unit operates in a vertical position, and its shaft is driven from the cam, or magneto, shaft through suitable gearing. The case of the instrument measures approximately 3½ inches in diameter and 5 inches in height.

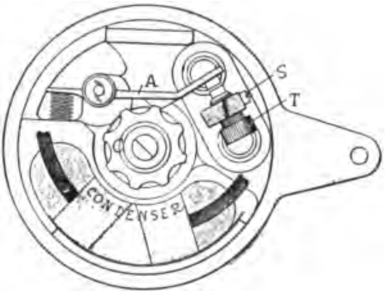


Fig. 358—*Westinghouse breaker mechanism*

The breaker mechanism is shown in Fig. 358. It is mounted beneath the coil, while the distributor mechanism is directly above the coil. Since the system operates on the closed-circuit principle the contacts normally are closed. In operation, rotation of the cam separates the contacts against the action of a small spring under the left-hand side of the arm, A, as shown in Fig. 358. This spring always is under compression. The cam is mounted loosely on the shaft, but a small pin in a collar, or hub, on the shaft against which the cam rests enters a hole in the cam and provides the necessary driving connection. The breaker mechanism operates equally well in either direction, and a backward travel of approximately 48 deg. is possible without causing the contacts to separate, which might result in a disastrous back-fire of the engine.

The condenser is mounted close to the breaker mechanism in a special compartment cast integral with the main base plate. This compartment is on the same level as the breaker mechanism, but on the opposite side of the shaft, as shown in Fig. 358. The condenser, coil and breaker are inclosed in a tube of Bakelite Micarta, which forms the body of the unit. Several openings are cut in the lower end of this tube to provide a means of making the necessary internal electrical connections and to give access to the breaker mechanism for inspection, cleaning and adjustment. A short thin tube is placed over the main tube, forming a cover for the openings in the large tube. This short tube may be raised directly upward, thus uncovering the openings.

The distributor is the same as that used in all the Westinghouse systems, in which a circular carbon brush makes contact with the various high-tension terminals which are included in the molded cover. One terminal of the secondary winding of the induction coil is connected to the carbon distributor brush by a metal ring mounted on a disk of insulation directly above the coil. The carbon brush extends through the end of the distributor arm and rests on the upper surface of the metal ring, which is connected electrically to the end of the secondary winding.

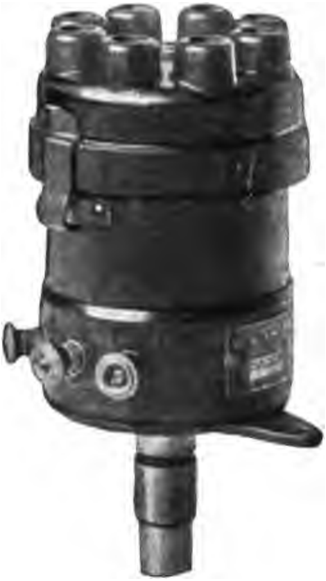


Fig. 359—External view of Westinghouse unit

The ignition switch is of the snap type and combines the lighting switch in one plate, which is mounted flush on the dash. Each time the ignition is turned the polarity of the circuit is reversed.

In adjusting the breaker the contacts should be dressed with a fine file and adjusted so that the maximum opening is .008 inch. A feeler gage is furnished with each outfit by the makers. The spark-plug gaps should be .025 inch. The distributor brushes should slide freely in their holder, and the spring should push the top brush out to extend from the holder about ¼ inch when the distributor plate is removed. The only lubrication required is two or three drops of oil about once a month in the oil cup on the side of the distributor unit.

What is termed a ballast coil is mounted in the back of the switch plate. This ballast coil is a small resistance in series with the primary winding of the coil, and its function is to protect the winding and prevent excessive drain on the battery should the engine happen to remain idle with the switch in the "on" position. If this coil should be broken the ballast terminals may be short-circuited temporarily with a piece of wire or with a standard 5-ampere fuse. An external view of the device complete is shown in Fig. 359.

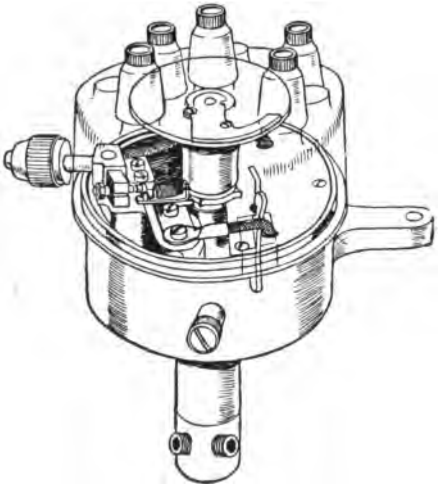


Fig. 360—Inter-relation of parts in Philbrin system

Philbrin

The Philbrin ignition system, manufactured by the Philips-Brinton Co., is both a single- and continuous-spark system. Either type of ignition may be used at will. The inter-relation of the various parts of the combined breaker-distributor unit is shown in Fig. 360. The distinctive feature of the system is the breaker, which supplies a single spark of great intensity, the quality of the spark remaining practically the same for all engine speeds.

The construction of the breaker is shown in Fig. 361 and its operation in brief is as follows: Rotation of the cam C, which is in effect a series of tiny triggers, pushes out the arm A, thus closing the contacts, which normally are open. When a trigger passes the arm the contacts are separated by the spring S instantly. The contacts are held together for approximately 3½ degrees of the revolution of the cam. It is this breaker mechanism that gives the single spark. If the cam is rotated the wrong way the triggers simply push the arm A out of the way, it being mounted in a specially-shaped hole in its supporting member, as shown in Fig. 362. The continuous spark is controlled not by the breaker mechanism but by a tiny vibrator of special form contained within the switch assembly.

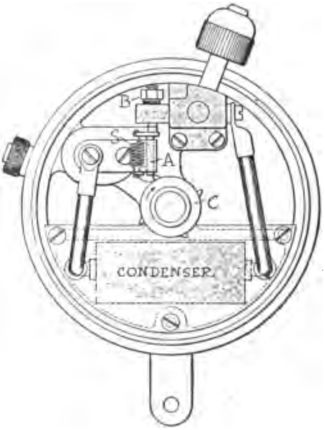


Fig. 361—*Top view of Philbrin breaker mechanism*

The vibrator operates at four to five times the speed of the ordinary vibrator. As long as the engine is running a continuation of sparks is produced, and this stream is distributed, as are the sparks from the single-spark portion of the system, by the distributor mechanism. The distributor has a long arm with a blade of peculiar force. This blade does not touch the high-tension terminals molded into the Bakelite cover but passes in very close proximity to the terminals, and the spark passes a small air gap. The reason for this long blade is to insure a continuous stream of sparks at the plug during a considerable portion of the piston travel. This stream of sparks is an advantage when the engine is cold or the carbureter is slightly out of adjustment, for it practically insures firing the mixture.

The Philbrin switch provides for two sources of current, the usual storage battery and an auxiliary set of dry cells, the arm of the switch being moved in one direction for the storage battery and in the opposite direction for the dry cells. The lever which controls the operation of the continuous-spark and single-spark operations is a small continuously rotary plug. This plug is marked alternately M and S, signifying whether the main or secondary systems are in operation. This special switch also reverses the polarity of the circuit each time it is turned, thus increasing the life of the contacts. The ignition coil is mounted in a waterproof case and may be mounted on the dash or, in some installations, directly with the distributor mechanism.

The system has but one adjustment, and this has to do with the opening of the contacts on the main, or single-spark, system. The gap between the contacts should be from .025 to .030 inch. The method of making the adjustment is obvious from an inspection of Fig. 362. The vibrator for the secondary system is housed in the switch assembly and will never require any adjustment. The manufacturers strongly urge that it never be touched. An external view of the Philbrin combined breaker distributor unit is shown in Fig. 363.

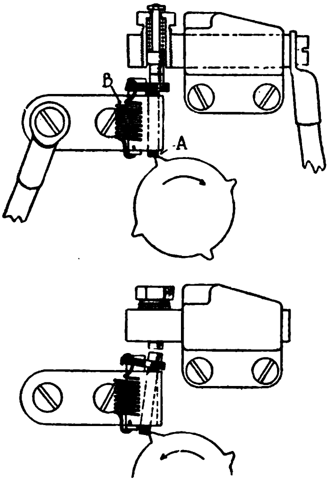


Fig. 362—*Operation of Philbrin breaker mechanism*

Delco System

The earlier ignition systems manufactured by the Dayton Engineering Laboratories Co. operate on the open-circuit principle. A top view of one of the interrupters is shown in Fig. 364, and its operation is as follows: The movable contact is carried on a straight spring blade C, to which there is attached a bent spring blade B, held against the surface of the cam by the coiled spring E. The spring C is placed, when properly adjusted, under a slight tension due to the action of the springs B and E, and the movable contact on the spring C is held away from the stationary contact D. When the projection on the spring B strikes the projections on the cam, the end of C moves toward the stationary contact and the contacts close. As the projection on the spring B passes the hump on the cam, the action of the spring E draws B back suddenly and the end of B strikes C and the contacts are quickly opened. The duration of the contact, of course, will depend upon the speed of the cam, which, of course, depends upon the speed of the engine.

In the later models of the battery ignition systems manufactured by the Dayton Engineering Laboratories Co. the closed-circuit principle is employed. A top view of the interrupter is shown in Fig. 365, and its operation is as follows: The arm B carries the movable contact D, which is normally in contact with the contact C. A piece filer is mounted on the arm B, which bears against the surface of the cam and is lifted by the projections of the cam against a small flat spring which is held by the inner wall of the housing. The stationary contact C is adjusted by the screw and held in place by the lock nut N. These contacts should be so adjusted that when the filer block mounted on B is on top of one of the humps on the cam, the contacts should open sufficiently to allow the gage on the wrench, provided with the system, to close the gap. The method of using the gage in adjusting the contact points is shown in Fig. 366.

Fig. 363—*External view of Philbrin combined breaker-distributor unit*

The timing of the spark may be adjusted by moving the cam A with respect to the shaft upon which it is mounted, which is done by loosening a screw in the end of the shaft and again tightening it after the cam has been moved the desired amount. Turning the cam in a clockwise direction, or toward the right, advances the time of ignition, and counter-clockwise, or to the left, retards it.

The Resistance Unit Function

Should the ignition switch be left closed when the driver leaves the car, there is a likelihood of the contacts on the interrupter being left in the closed position, and if these contacts are closed, the battery will continue to discharge, which will result in its being completely exhausted if the discharge is allowed to continue for a sufficient time. To prevent this waste of energy and possible damage to the coil, a resistance has been introduced into the primary circuit. This resistance unit is shown in the upper left hand corner of Fig. 367. The unit consists of a small open coil of high resistance wire wound upon a porcelain spool. All the current passes through this resistance unit, but owing to the extremely short period it continues between interruptions, due to the opening of the contact points, the resistance wire remains fairly cool. When the ignition switch is left closed and the engine stops with the interrupter contacts closed, the current is then continuous and of greater effective value, and it causes the resistance wire to become heated to a red heat in a very short time. At this high temperature the resistance of the wire is much greater than at a lower temperature, so that it does not permit as much current to pass through the primary winding of the coil as would pass if the resistance of the wire remained unchanged.

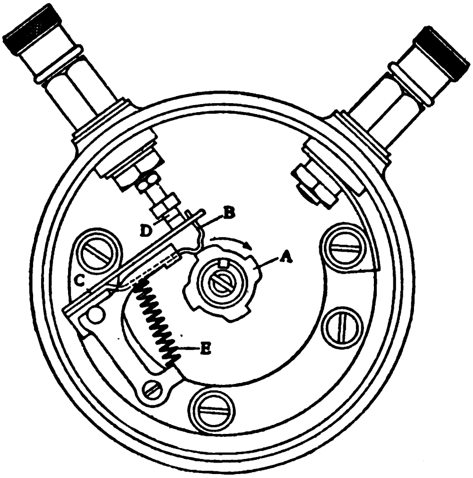


Fig. 364—Top view of Delco open-circuit type of interrupter

Delco Interrupter

A dual type of interrupter is shown in Fig. 368. It has two independent sets of interrupter contacts, one for the battery and one for the magneto. The operation of this interrupter is the same as the other types except an additional set of contacts is provided.

The earlier Delco ignition systems were provided with a way to produce a series of sparks for starting and a single spark when running. This device is no longer a part of their standard equipment, but its wide use on the thousands of cars at the present time warrants a description of its operation. The relay and a diagram of its connections are shown in Fig. 369. It consists of an electromagnet provided with two windings, one of large wire and one of small wire, similar to the cutouts. The magnetic effect of the coarse wire is greater than the magnetic effect of the fine wire, and it exerts sufficient magnetic pull on the armature when at rest to draw the armature toward the end of the armature core, which breaks the contacts at C.

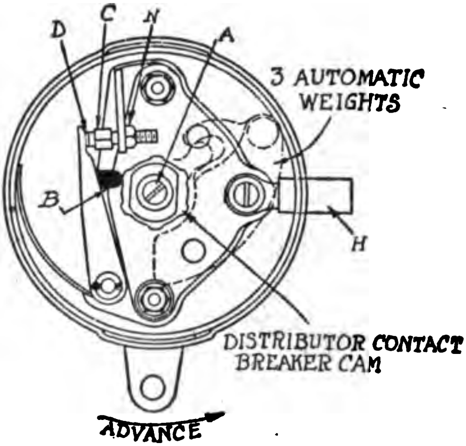


Fig. 365—Top view of Delco closed-circuit type of interrupter

The construction is such that the current ceases to flow through the winding when the contacts C are open. The fine winding is connected to the contacts so that it holds the armature of the relay open after the circuit of the coarse winding is broken at the contacts C, and this winding is known as the "holding coil." The magnetic pull of the fine winding is not sufficient to draw the armature down from the position of rest, but is strong enough to hold it down after the coarse winding has pulled it down. The arc at the contact C is suppressed by the condenser, which also increases the speed of operation. A three-way switch is provided, which has a point for starting and one for running and a neutral point. When the switch is thrown to the starting point, the relay operates continuously just the same as a vibrator and produces a series of sparks; when the switch is on the running point, the fine winding is energized and a single spark is produced.

A special interrupter is provided for extremely high-speed engines. These interrupters are provided with two sets of contacts and a special cam, depending upon the number of cylinders. Each set of contacts is provided with a separate relay, and the circuit is closed through the two relays alternately, thus giving each magnetic interrupter more time in which to open and close the circuit. The connections of a system of this type are shown in Fig. 370 and a complete wiring diagram is shown in Fig. 371.

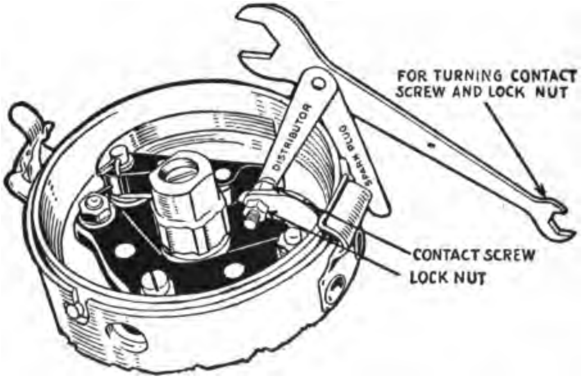


Fig. 366—Method of using gage in adjusting contact points of Delco interrupter

Delco Ignition Relay

Two methods of connecting the Delco ignition relay are shown in Figs. 371 and 372. In Fig. 371 the relay winding of large wire and the contacts shown at C in Fig. 369 are in series with a set of interrupter contacts on the dual interrupter. When the interrupter contacts are closed, a current is produced by the dry cells in the coarse winding of the relay, and its armature is drawn down, which cause the primary circuit to open and thus produce a spark at the plug. The armature of the relay is disengaged as soon as the contacts at C are opened, and the armature will continue to vibrate indefinitely as long as the interrupter contacts are together, unless the fine wire winding of the relay is energized in some way. The fine wire winding of the relay will be energized if this switch is depressed, and a series of sparks will be produced so long as the interrupter contacts are closed. Thus in starting the switch which normally connects the points 6 and 7 will be held in an open position.

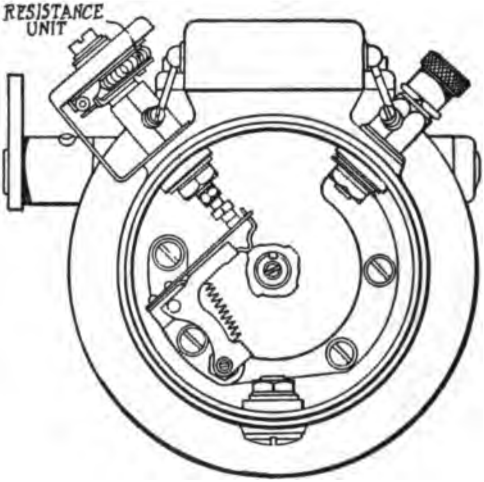


Fig. 367—Delco interrupter with resistance unit

The method used in connecting the Delco ignition relay on what was called the Junior system for 1914 is shown in Fig. 372. The ignition switch completes the primary circuit, and when the relay is used in this manner, the holding coil circuit is completed through the interrupter contacts. A vibrating spark is obtained as long as the timer contacts are open, and the timing of this vibrating spark is obtained by the action of the contacts upon the holding coil itself. This method of using the relay causes much later ignition than the method previously described.

When the armature B, Fig. 369, is pressed down, there should be absolutely no motion of the blade G, Fig. 373, carrying the lower contact. The gap at C should be approximately .005 in. When the blade A is lifted carefully by hand, the contact at C should open to the same gap as before, namely, .005 inch. The contacts at C should be clean and their surfaces perfectly parallel.

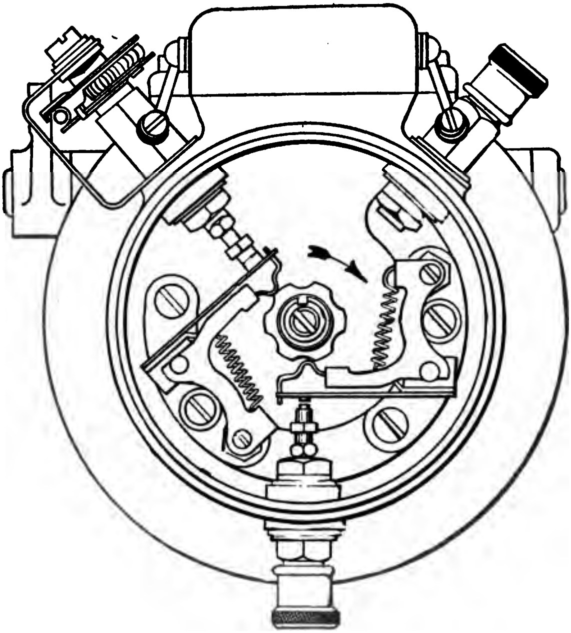


Fig. 368—*Delco dual type of interrupter*

There are two adjustments to the relay, as follows: The air gap 1 shown in Fig. 369, which increases the distance at C also, and the tension exerted by the spring A, Fig. 373, on the contacts C. Small adjustments may be made in the gap between the contacts at C, but in no case should this distance be increased very much over

.005 inch. If adjustment of this gap does not give a spark of sufficient intensity, it will be necessary to increase the tension of the spring. The tension in the spring can be increased by crowning as follows: The spring is held loosely between the jaws of a pair of duck-bill pliers near the end, which is screwed down to the frame, and the pliers then are moved along the spring with a downward pressure and a slight twist to the right as shown in Fig. 373. This operation, properly performed, will give the spring the form shown in Fig. 374, and the tension will be increased noticeably. Be sure the armature is free on its pin.

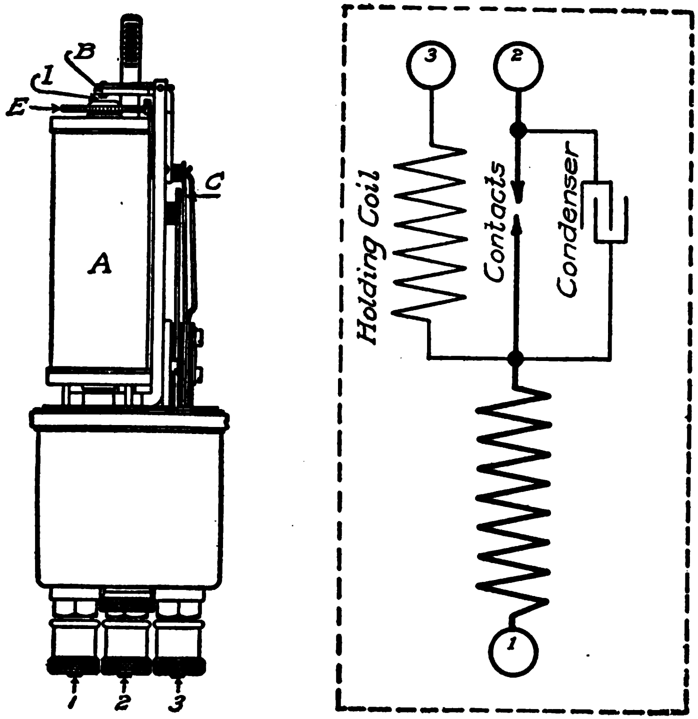


Fig. 369—*Delco ignition relay and internal connections*

Typical Delco distributors for four-, six-, eight- and twelve-cyl-

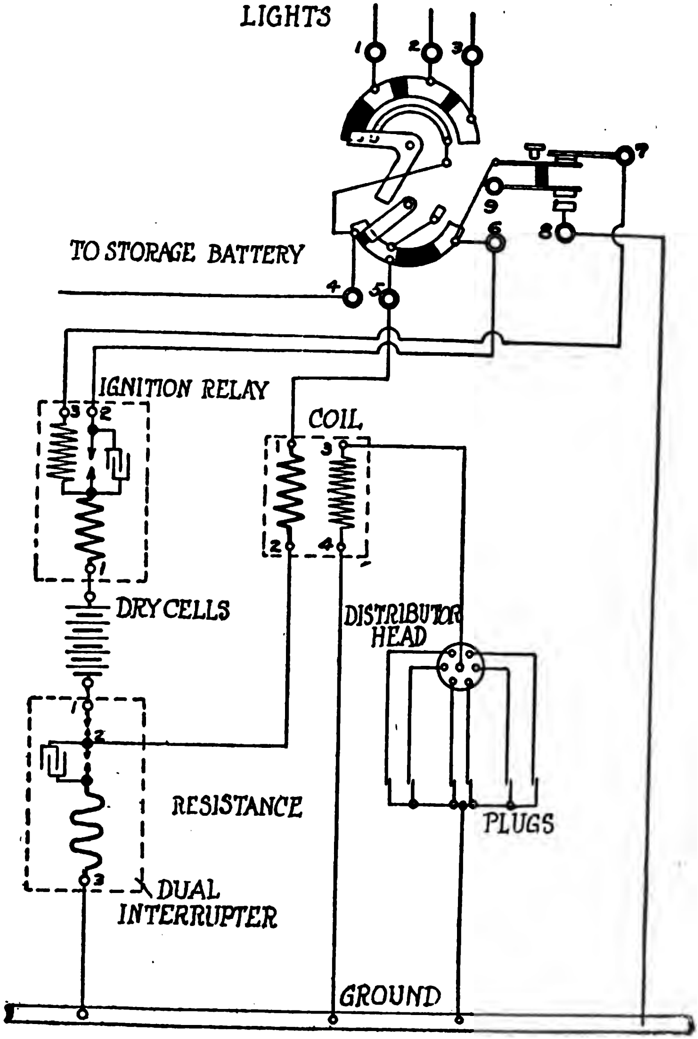


Fig. 371—Wiring diagram of Delco ignition system with dual interrupter and ignition relay

inder installations are shown in Figs. 375, 376, 377 and 378. The one shown in Fig. 375 is used on the 1917 Dodge Brothers car; the one shown in Fig. 376 is used on the 1917 Hudson; the one shown in Fig. 377 is used on the 1917 Cadillac, and the one shown in Fig. 378 is used on the 1917 Packard.

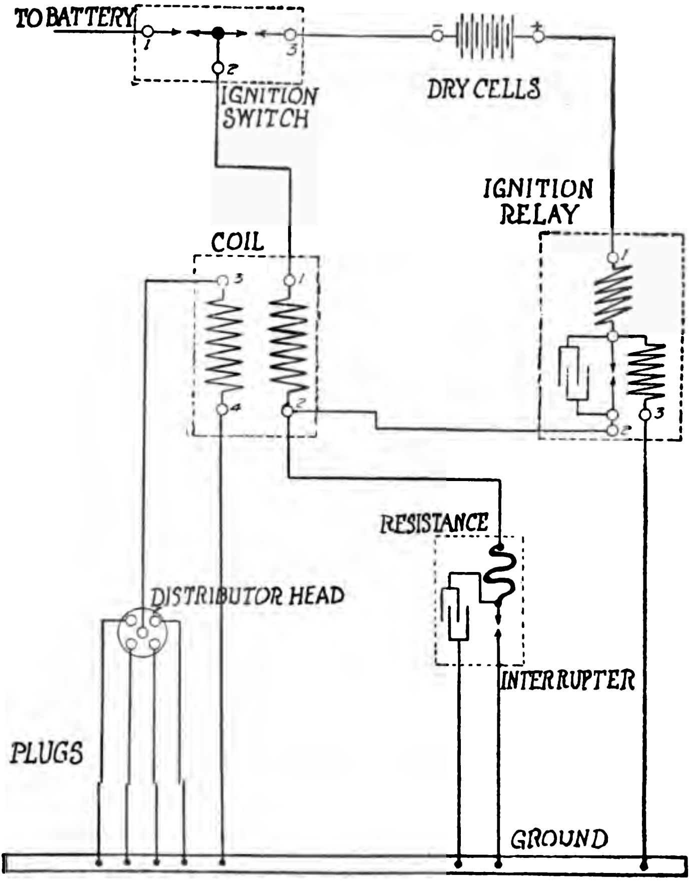


Fig. 372—Wiring diagram of Delco Junior ignition system, showing connections

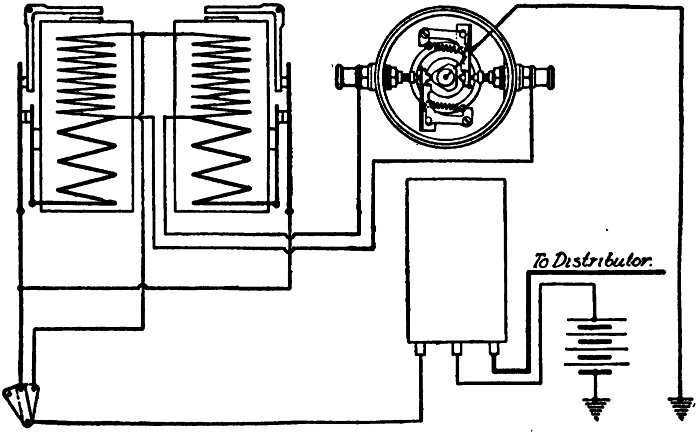


Fig. 370—Delco special interrupter for high-speed engines

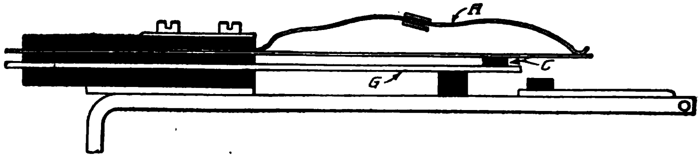


Fig. 373—Method of crowning spring on Delco ignition relay

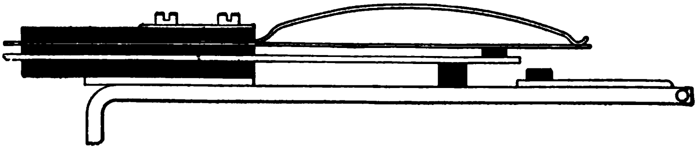
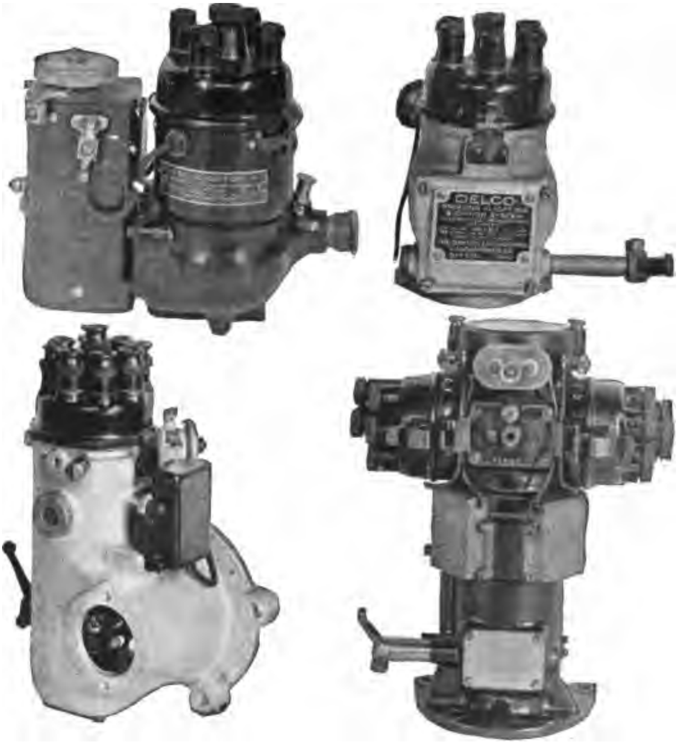


Fig. 374—Proper appearance of springs on Delco relay

Single Ignition System

The single ignition system, as its name indicates, is a system of ignition employing only one source of electrical energy, one set of electrical connections and one set of spark plugs in the engine cylinders. The source of the electrical energy may be any of the various sources used in the different ignition systems, such as dry or storage battery and low-tension or high-tension magneto. A good example of a single ignition system is found on the Ford car as it is delivered by the manufacturer. Energy for ignition in this case is derived from a special form of low-tension magneto and is increased in intensity or pressure by a vibrating coil from whence it is distributed to the various cylinders. In this par-



Figs. 375 *to* 378—*Typical Delco distributor installations. Fig.* 375, *upper left,* 1917 *Dodge; Fig.* 376, *upper right,* 1917 *Hudson; Fig.* 377, *lower left,* 1917 *Cadillac, and Fig.* 378, *lower right,* 1917 *Packard* ticular case no distributor is used in the high-tension circuits or leads to the various spark plugs, but the interrupter, or timer, in the primary circuit serves as a distributor. An amplified diagram of the Ford ignition is shown in Fig. 379. When a battery is installed this system then becomes a dual system as will be explained later.

The single ignition system must not be confused with the term single-unit system. The single-unit system is one in which the starting, generating and ignition operations are performed by one unit. In such a system the same armature fields are used for both the generator and the motor but a separate winding usually is employed for each of the two functions. The generator supplies energy for charging the storage battery, which in turn is used for ignition and operating the starting motor.

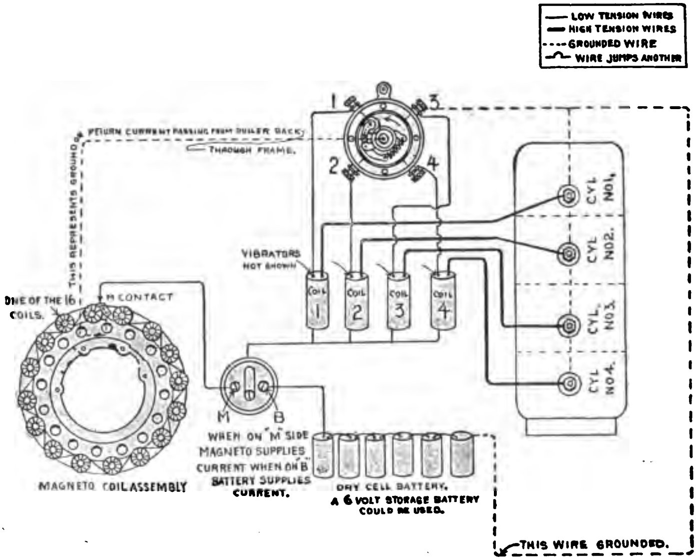


Fig. 379—*Wiring diagram of single ignition system as used on Ford cars*

Dual and Double Ignition

The various magneto and battery systems of ignition may be combined into what are called dual and double systems. A four-cylinder engine is shown equipped with four different systems of ignition in Fig. 380, and a brief description of these different systems will be given before their various combinations are explained.

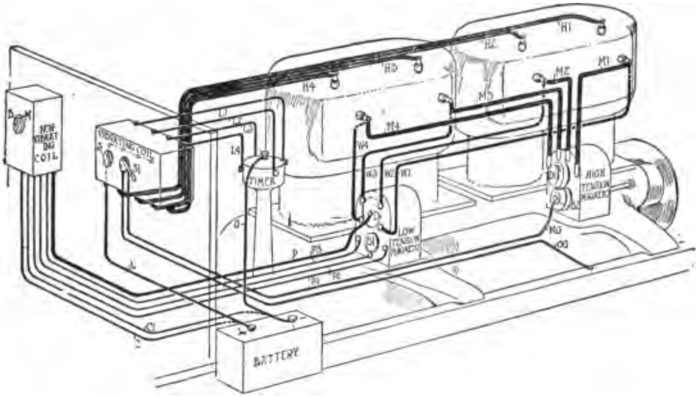


Fig. 380—*Four high-tension ignition systems installed on one four-cylinder engine*

A high-tension magneto is shown toward the front end of the engine with its high-tension wires leading from the distributor to the four spark plugs marked M1, M2, M3 and M4 respectively. From the terminal on the end of the magnets, marked B2, a wire MG runs to the switch S1 mounted on the vibrating coil. A second wire GG runs from this switch to the frame of the car, and if the switch is closed the terminal B2 will be connected to ground and the high-tension magnets will supply ignition current to the set of spark plugs to which its high-tension wires are connected.

A high-tension battery system provided with timer and vibrating coils for each cylinder also is shown, and the circuits may be traced as follows: Starting with the positive terminal of the battery pass along the wire L to the switch S on the vibrating coil, then through the different primary windings and vibrators and along the wires L1, L2, L3 and L4 to the head of the timer, and from the center of the timer head along the wire G to the negative terminal of the battery. The high-tension wires lead from the under side of the vibrating coil to the four spark plugs H1, H2, H3 and H4, respectively, which are mounted in this case in the top of the engine cylinders. If the switch S is closed, current will be supplied to the different primary windings, in turn depending upon the order in which contact is made in the timer. The vibrator in each primary circuit will produce a series of sparks in the secondary circuit as long as the timer circuit for that particular primary circuit is closed.

A third system consists of a low-tension magneto in combination with a non-vibrating coil, and the circuits of this system may be traced as follows: Wires P1, P2 and P3 connect the armature winding of the low-tension magneto to the non-vibrating coil and one terminal of the secondary wiring to ground, and if the switch on the point of this coil is thrown to the position marked M a circuit will be completed through the primary winding of the coil. The wire P connects one terminal of the secondary winding of the non-vibrating coil to the center terminal of the distributor on the low-tension magneto. The low-tension current of the magneto will pass through the primary winding of the coil and when it is interrupted suddenly by the breaker on the magneto a high-tension current will be produced in the secondary winding, which will supply energy to one of the spark plugs, depending upon the position of the distributor contact or arm. A fourth system is provided which is identical to the one just described with the exception that the battery replaces the winding on the magneto.

If the first two or the last two systems just described were combined we would have what is called a dual system. In each of these dual systems the same set of spark plugs and high-tension distributors are used. Other combinations, of course, may be used in forming a dual system.

If the vibrating coil timer and battery, with spark plugs, H1, H2, H3 and H4, and the high-tension magneto, with its spark plugs, M1, M2, M3 and M4, were combined on a single engine, the combination would be called a double system. A second double system

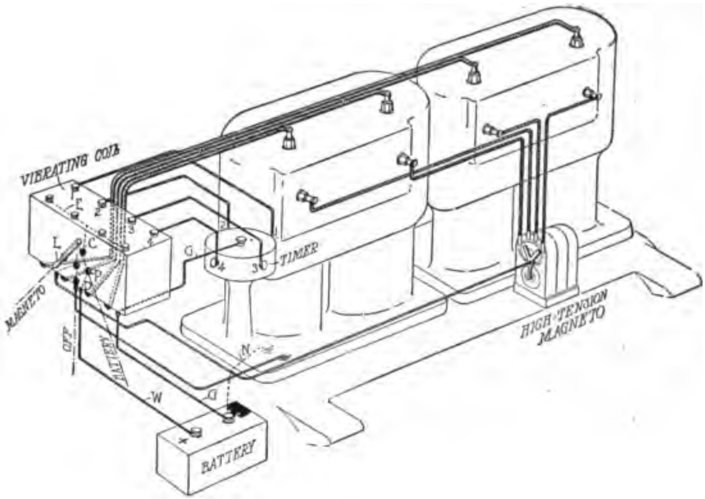


Fig. 381—*Double ignition system using a high-tension magneto with a vibrating coil timer and battery*

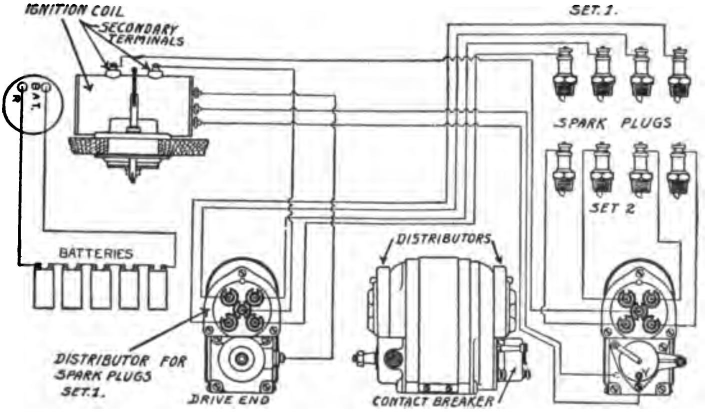


Fig. 382—*Wiring diagram of Remy in which two sparks are provided for igniting the gas at the same time* could be formed by combining the low-tension magneto, non-vibrating coil, timer and plugs M1, M2, M3 and M4 with the vibrating coil timer and battery. Other combinations are used for combining the various single ignition systems into dual and double systems. The wiring diagram of a double system using a high-tension magneto in combination with a vibrating coil timer and battery is shown in Fig. 381.

Two-Spark Ignition

Two-spark ignition simply means that two sparks are provided for igniting the gas mixture in the cylinder at the same time, the object being to increase the power and speed. Magnetos used in providing two-spark ignition usually are provided with two separate distributors and in some cases with two windings served by a common breaker. The wiring diagram on a Remy two-spark magneto is shown in Fig. 382.

CHAPTER XXIV

Spark Plugs

THE spark plug is one of the most important parts of the ignition systems, and no matter how carefully the remainder of the system is constructed and installed the successful operation of the system is entirely dependent upon the spark plug. The spark plug is a very simple device which consists of two terminal electrodes carried in a suitable shell, which is screwed into an opening provided for it in the cylinder wall. A section of several typical spark plugs are shown in Fig. 383. The secondary, or high-tension, wire from the ignition device is connected to a terminal at the top of the plug, which usually forms the central electrode and extends down through the plug. This center member is insulated from the shell by a bushing of some form of insulating material. The electrode and bushings are fastened in a steel shell or body, which is provided with a threaded end at the bottom, by which it may be fastened into the wall of the combustion chamber. The insulating materials commonly used are porcelain, mica, steatite and lava. Porcelain and mica are used more than other insulations, because their mechanical and electrical characteristics make them better suited for this. When porcelain is used some form of insulating packing must be used to keep it from contact with the metal shell of the plug. This packing is required, because the porcelain and steel have different coefficients of expansion and it is absolutely imperative that some flexibility be provided at the joints to permit the two materials to expand differently when heated.

In the early forms of spark plugs the insulating material filled the shell at the lower, or sparking, end of the plug, which afforded a direct path for the current to travel over just as soon as this small surface was coated with carbon. It was nothing uncommon to have to clean this type of plug in less than 100 miles of running.

This objectional feature was greatly improved by allowing a space between the insulation surrounding the central electrode and the outer shell. This simple arrangement constitutes a basic parallel under which all spark plugs are manufactured.

Arrangements of Electrodes

The arrangement of the electrodes varies considerably and may take the form of open points as in Fig. 384, a bridge as in Fig. 385, several points as in Fig. 386, an inclosed arrangement as in Fig. 387, etc. Certain advantages are claimed for the plugs provided with more than one gap. This advantage, however, is more theoretical than practical, since the electrical current will bridge the gap offering the least resistance and should one of the gaps become shorted, by a particle of carbon, all of the gaps will be shorted.

Series Spark Plug

In the series type of spark plug the spark occurs between two central electrodes each of which is insulated from the shell of the plug. A plug of this type is shown in Fig. 388. The objects of such a plug is to furnish a means of providing two sparks in each cylinder by a standard ignition system. A plug of this type and a standard type of plug are mounted in the wall of the combustion chamber. The high-tension wire from the ignition system is connected to a terminal of the series plug, and the second terminal is connected to the central electrode of the standard plug, thus connecting the gaps in the plugs directly in series. The object of such an arrangement is to provide double-spark ignition. Experiment has shown a slightly increased power when two sparks occur simultaneously in different parts of the combustion chamber, especially in the T-head type of engine cylinder in which the two plugs can be located in the oppositely-placed valve parts. As the great majority of engines are of the L-head type and since the advantages of the series type of spark ignition at least are so very slightly greater than the single-spark type, there is very little advantage to be gained in its use.

The series type of spark plug may be used as a grounded return type by an attachment as shown in Fig. 389. All this attachment does is to form a metallic conductor between one of the terminals or electrodes and the shell of the plug which is, of course, in electrical contact with the engine cylinder. The high-tension ignition lead, of course, is connected to the terminal on the spark plug to which the special attachment is not connected.

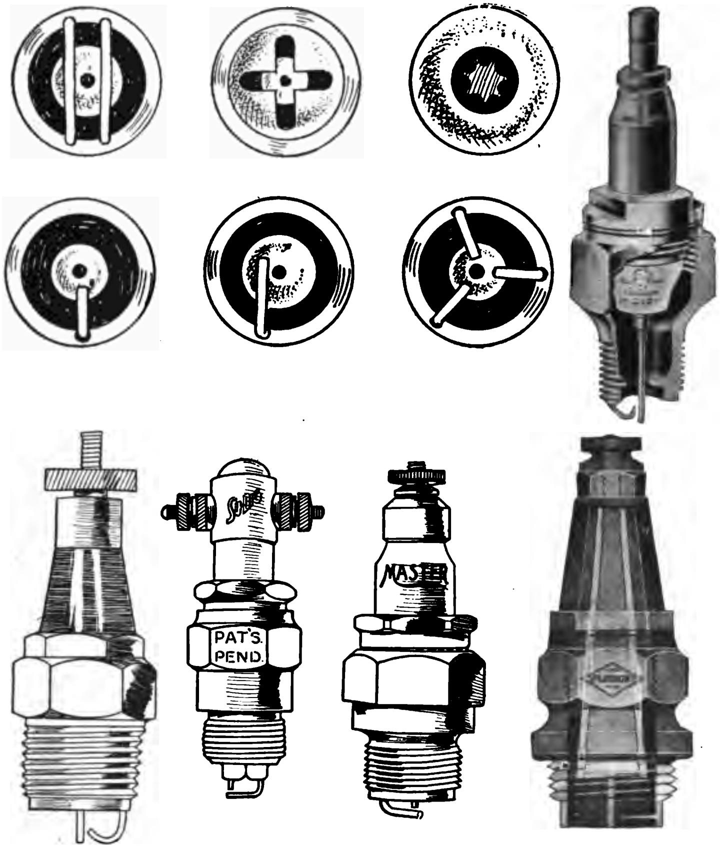


Fig. 383—*A section of typical spark plugs, showing, upper left, typical ends; upper right, Red Head; lower left, Kingston, Su-Dig and Master; and lower right, Splitdorf*

Magnetic Type of Plug

This type of spark plug was developed with a view to overcoming the trouble in the operation of the make-and-break plug as used on the low-tension ignition systems. A section through a plug of this type is shown in Fig. 390, and its operation is as follows: A solenoid, A, surrounds a plunger, C, whose lower end is held in contact, D, by a spring, B. The magnetic pull due to a current in the winding A lifts the plunger and causes a spark at D. Plugs of this type have found little use on the motor car, as the high temperatures to which they are subjected in such applications draw the temper of the plunger spring and often seriously injure the insulation of the solenoid winding. Their use has been more extensive in connection with stationary engines where the temperatures are much lower.

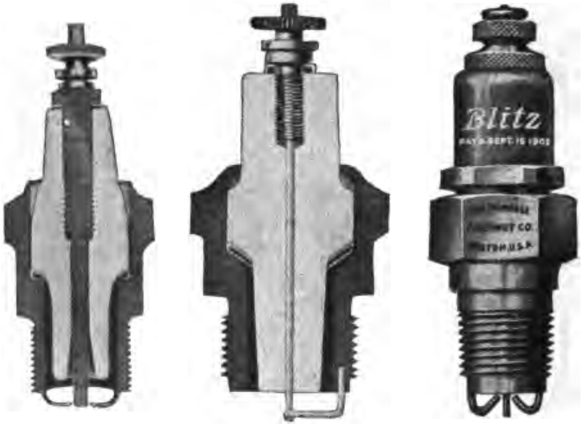


Fig. 383 *continued—Other typical spark plugs, respectively Bosch, AC and Blitz*

Waterproof Plugs

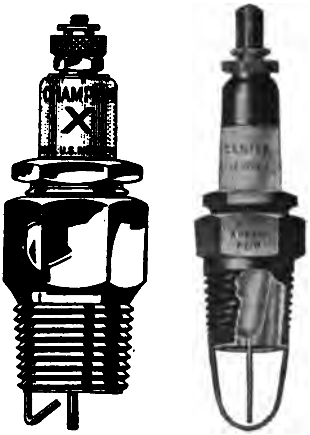
In certain applications of the gasoline engine, as on motor boat engines in particular, the spark plugs are likely to become short-circuited from the spray or dampness. A special plug is provided to prevent such an occurrence, and a plug of this type is spoken of as a waterproof type. The only difference in the construction of a plug of this type and the ordinary plug is the addition of a protective hook of hard rubber or other suitable insulation placed over the connections. A plug of this type is shown in Fig. 391.

Priming Plugs

The priming type of spark plug is one provided with a pet cock as shown in Fig. 392. This plug usually is used on engines which are not regularly equipped with priming or compression-release cocks.

Airplane Type

The construction of the airplane type of spark plug anticipates the development of great heat. A plug designed for this particular use is shown in Fig. 393. The insulation core C is built up of mica washers and has square shoulders. These square shoulders afford two gasket seats, and when the core is clamped in the shell by the check nut E it is centered accurately and a tight joint is formed. This construction gives a plug shorter than with conical fits and thus improves the heat radiation through the stem. The lower end of the shell has a baffle plate, O, which tends to keep oil from the mica. Perforations, L, in the baffle



Figs. 384 *and* 385—*Champion electrode of open points, left, and Center Fire bridge*

Fig. 386—*Electrodes with several points on the Stewart V-Ray and Bosch* plate prevent burnt gases from being pocketed behind the plate and pre-igniting the charge. The stem P is made of brass or copper for superior heat conductivity, and the electrode J is swedged in the bottom of the stem, as shown at K. The shell is finned, as shown at G, to provide greater heat-radiating surface. A fin, F, at the top of the stem also increases the radiation of the heat from the stem and electrode. The top of the fin and portion is countersunk slightly, and the stem is riveted into it, thereby preventing leakage past the threads on the stem. The finned portion is necked at A to take a slip terminal. In building up the core a small section of washers, I, is built up before the mica insulating tube D is placed on. This construction gives a better support for I. The baffle plate O is bored to allow the electrode J to pass through, and the clearance between the baffle plate and the electrode is larger than between the firing joints, as there is no danger of spark jumping from electrode to baffle plate. This plug is supplied with or without the finned portion.

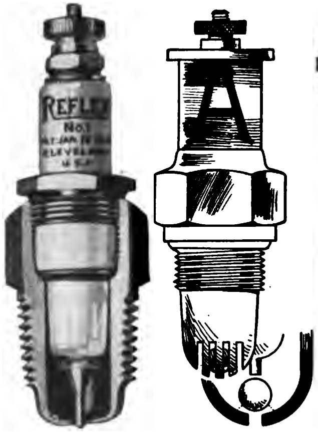
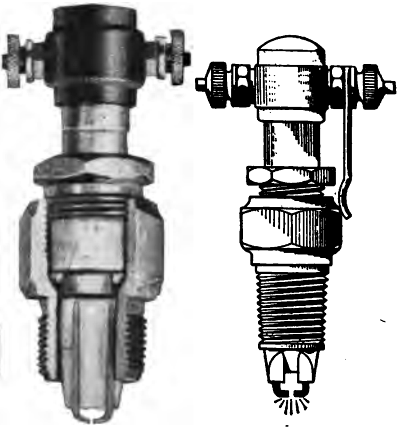


Fig. 387—***Plugs with inclosed arrangement, the Reflex and D & D Fouless***

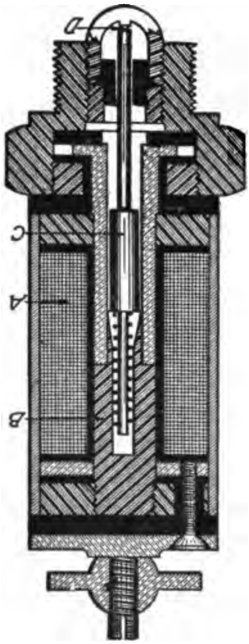


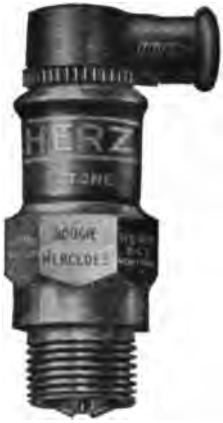
Figs. 388 ***and*** 389—***Efficiency spark plug and special attachment for series spark plug***

Plug Threads

The straight-threaded plug is standard European practice. The thread itself is usually fine pitch. This type of plug is screwed in tight against a gasket of copper or asbestos to prevent breakage. Foreign-made plugs usually are referred to as metric plugs, as the thread dimensions are based on the metric standard.

All spark plugs in this country were made first with an iron-pipe thread, which has a taper of ¾ inch to the foot, and the plug is screwed into the cylinder as far as the taper will permit, no gasket being used to hold the compression. This is not altogether satisfactory, and since the electric system is not used very extensively in this country, a separate type has been developed and is known as the S. A. E. standard plug. The diameter and thread on this plug both are somewhat larger than those used abroad.





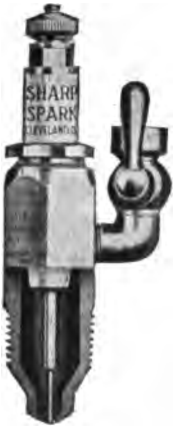


Fig. 390, left—Magnetic type of spark plug. Fig. 391, upper left—Waterproof type of spark plug. Fig. 392, upper right—Priming type of spark plug

The S. A. E. standards for spark-plug shells are illustrated in Fig. 394. All dimensions below the shoulder are identical for both sizes of spark-plug shells. The spark plugs can be turned in by hand, using a wrench only for final tightening, if the taps are made to dimensions as follows: Diameters, nominal dimensions, outside, A, .875 in.; pitch, B, .839 in.; root, C, .803.

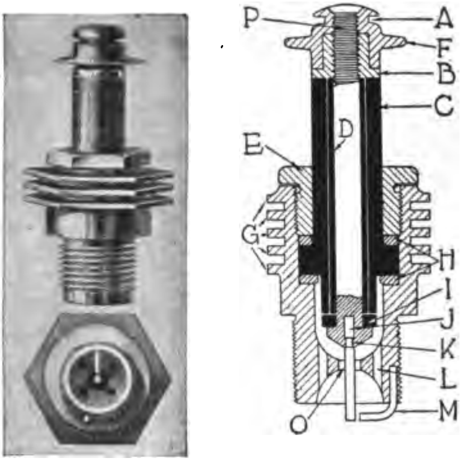
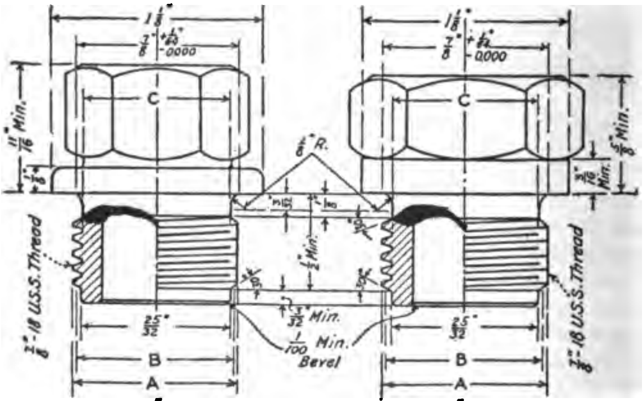


Fig. 393—Airplane type of spark plug, the Pittsfield, showing the structure in cross section



SMALL HEX. 7/8" ACROSS FLATS **LARGE HEX. 1 1/8" ACROSS FLATS**

Fig. 394—S. A. E. standard dimension for spark-plug shells

The spark plugs should be placed in the wall of the combustion chamber in such a position, when possible, that the spark produced between the electrodes will be directly in the path of the entering fresh gases from the carbureter. Several methods of installing spark plugs are shown in Fig. 395. In the cut marked A the plug is screwed into a threaded hole in the valve cap, and in this particular case the electrodes of the plug are in a pocket. In the cut marked B the position of the spark plug has been lowered by cutting a recess in the top of the valve cap, which allows the electrodes of the spark plug to extend down so there is ample clear space around them. The installation shown at A is much more troublesome than the one shown at B due to the fact that the electrodes are more likely to become short-circuited by accumulation of oil or carbon, and some of the burned gases may remain in the pocket and thus prevent the fresh mixture from the carbureter from getting in around the spark gap.

The two mountings shown in cuts C and D are practically the same so far as the position of the spark gap in relation to the combustion chamber is concerned, but their mechanical mounting in the cylinder wall differs. The method of mounting shown at C does not permit the heat to be transferred as readily to the cooling jacket as the installation shown at D, and hence the plug shown at D will be somewhat more efficient.

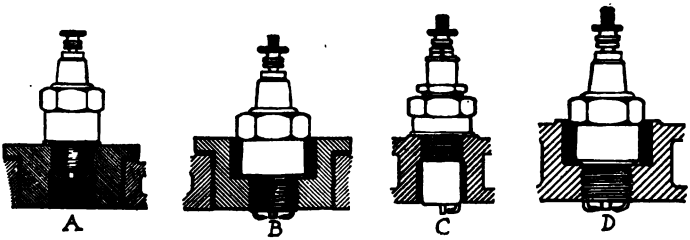


Fig. 395—Several methods of installing spark plugs

Every spark plug should be provided with some form of terminal at its outer end by which the end of the high-tension wire may be connected electrically to the insulated electrode of the spark plug. This terminal, as found on spark plugs at the present time, assumes several different forms, but they must all meet one main requirement, that is, the electrical connection must be made securely so there is no chance of an open circuit at this point. The chief difference in the design of the different terminals is in the manner of fastening the wire or terminal on the end of the wire to the plug.

Gap Between Electrodes

The gap between the electrodes of a spark plug should be adjusted to approximately $\frac{1}{32}$ inch for spark plugs used with battery ignition system, and to approximately half this amount, or $\frac{1}{64}$ inch, for spark plugs used with magneto ignition systems. Several companies provide a thickness gage to use in adjusting the distance between the electrodes so that the best results may be obtained with that particular system. The space between the terminals of the electrodes of the spark plug offers a very high resistance to the flow of electricity until sufficient pressure has been applied to produce an arc between the electrodes, which greatly lowers the resistance. This arc will not be produced unless sufficient pressure is applied. The pressure required to produce an arc between the electrodes of a spark plug depends upon the distance between the electrodes and the degree of the pressure of the gas in the combustion chamber in which the spark plug is mounted. The pressure required also depends upon the form of the electrode, that is, whether it is round, square, pointed, etc., at the end. The larger the gap between the electrodes, etc., the greater the electrical pressure required; likewise, the greater the pressure in the combustion chamber the greater the electrical pressure required to produce an arc. A spark plug which may appear to give a very good spark when it is tested outside the cylinder may not work at all satisfactorily when placed in the cylinder due to the high pressure in the cylinder.

CHAPTER XXV

Ignition Wiring and Timing

THE wiring for an ignition system may be divided into two main groups, low and high-tension wiring. The wires for the low-tension circuits are subjected to a relatively low voltage, and the insulation surrounding them need not be very thick to prevent serious leaks of electricity, which would reduce greatly the efficiency of the ignition system. On the other hand, the wires used in the high-tension circuits are subjected to a high voltage, and the insulation surrounding them must be of ample thickness and of such a character as to withstand easily this high voltage and thus confine the flow of the electricity to the path in which it is supposed to move, so that the ignition system may operate satisfactorily. The insulation used on the wires for both the low and high-tension circuits must possess ample mechanical properties, in addition to their electrical properties, to withstand the heat and mechanical abuse to which they will be subjected in ordinary use. The cross-sections of several of the different kinds of wires used in motor car wiring are shown in Fig. 396.

Great care always should be exercised in placing the various ignition wires on the car, so they may be subjected to the minimum mechanical abuse of the shortest length possible, run in such places and so protected that they will not be seriously injured by water, oil or heat.

The ends of all wires should be fastened securely at their ends to reduce to a minimum the likelihood of a loose connection or open circuit.

Timing Battery System

There is a difference between the time when the spark is made between the electrodes of the spark plug and when the combustion of the gas actually takes place. If the combustion of the gas mixture in the cylinder actually took place at the same instant the spark in the combustion chamber was produced then the proper place to set the timing mechanism would be that position which would cause the spark to occur at the top of the compression stroke of the piston in its travel up and down in the cylinder. There is, however, as stated above, a certain amount of time required for the gas mixture to burst into full explosion after the ignition spark occurs, but it is desirable to have the spark occur at such a time that the full combustion of the gas will take place when the piston is at the point of highest compression.

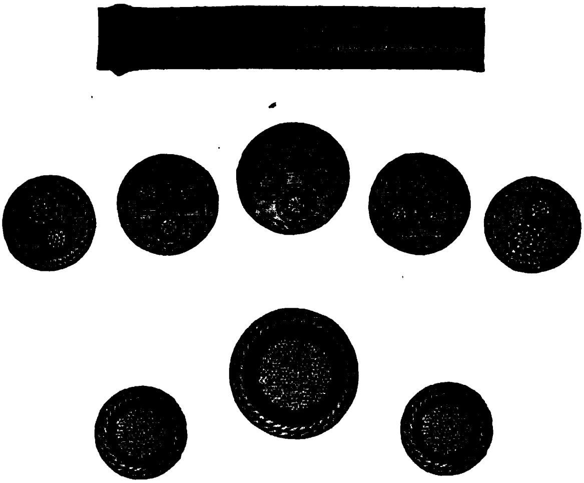


Fig. 396—Cross-sections of wires and cables used on motor cars

There are two main points to consider in setting the time of spark in relation to the position of the piston in its travel in the engine cylinder and these are: First, the kind of ignition system and, second, the speed at which the engine piston is traveling. If a coil and vibrator system of ignition is used, it is no more than natural to suppose that the actual time in making contact at the commutator and the time of action the vibrator will be greater than if a single contact system is used as in the case of the magneto or single-spark system. Hence, it is necessary to set the spark so it will occur a longer time before the top of the compression stroke than will be necessary when an ignition system that is less sluggish in action is used.

When the speed of the piston is low, or the engine is running slow, the time required for the piston to travel from a given point to the point of maximum compression will be considerably greater than the time required for the piston to travel the same distance when the piston is traveling at a higher rate or the engine is running fast. It readily is seen that the time the spark occurs in the engine cylinder in relation to the position of the piston must be changed as the speed of the engine changes. As the engine speeds up the spark should be caused to occur at an earlier time in relation to the position of the piston so there will be a full combustion of the gases in the engine cylinder when the piston is at its extreme travel. In order that the spark may occur at a later time in relation to the position of the piston the contact or interrupter controlling the spark should be moved in the direction of rotation of the shaft driving it. In practice moving the interrupter or contact device in the direction the shaft driving it rotates is called advancing the spark, while rotating the interrupter or contact device in the opposite direction is called retarding the spark.

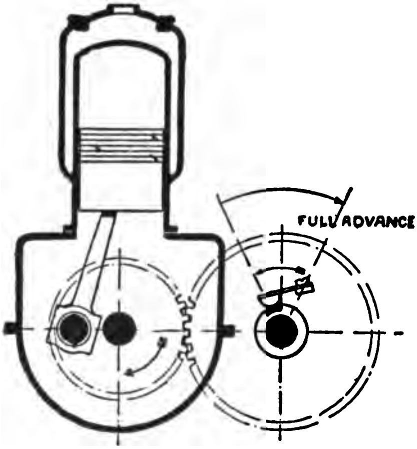


Fig. 397—*Spark fully advanced*

The meaning of these terms will be clearly understood by reference to Figs. 397 and 398, which show the spark fully advanced and fully retarded.

Space will not permit a complete description of the details of the method of timing all the various battery ignition systems, but the following main points must be kept in mind always. Make sure the contacts on your timer or the interrupter are operating at the proper time in relation to the position of the engine pistons when the spark lever is in its two extreme positions. Make sure the contacts on the timer are connected to the proper primary coils when a coil is used for each cylinder and that the secondary leads from these coils are connected to the proper spark plugs so the firing order of the cylinders will be correct. Make sure the connections from the distributor to the various spark plugs are correct. Inspect all the connections and wiring for apparent cases of trouble. The reader is referred to the book of instructions furnished by the manufacturer of the different cars for the details in setting the positions of the cam operating the interrupter or the timing contacts of the timer, etc.

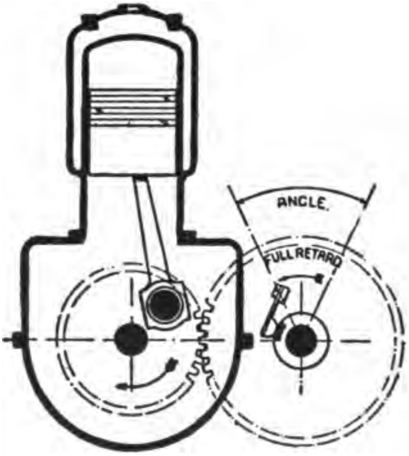


Fig. 398—*Spark fully retarded*

CHAPTER XXVI

Electric Signals and Accessories

DEVELOPMENT of starting, lighting and ignition systems has resulted in the installation on the motor car of a small electrical powerplant of considerable capacity, and, as a result, electrical energy is now available to a much larger degree than it was on the early cars, which usually were provided with a set of dry cells and at most a storage battery which had to be charged by removing part of the car. As a result of this, larger sources of electrical energy being available at all times, a great many useful electrical accessories have been developed to quite a high degree of perfection and add to the convenience and comfort in operating the car. Some of the more important of these electrical accessories are discussed briefly in the following paragraphs.

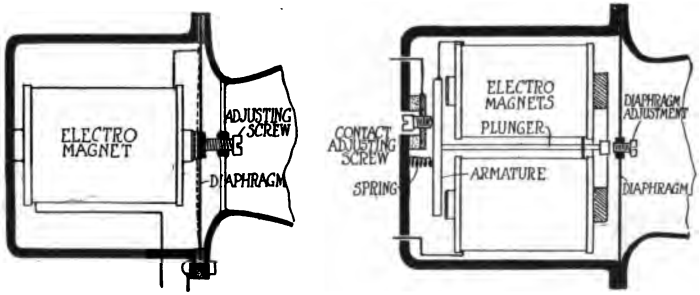
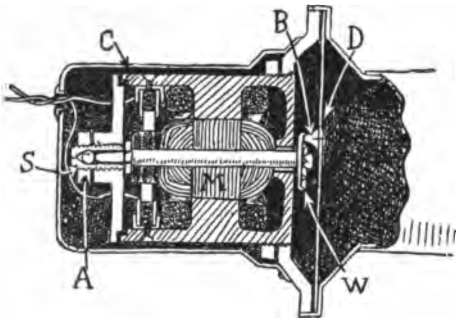


Fig. 399 *and* 400—*Buzzer-type electric horns in which the electromagnet acts directly upon the diaphragm, left, and through the medium of a plunger*

Electrical Alarms

Electrical alarms operate on two general principles: they may be of the buzzer type or of a mechanically-actuated diaphragm type. The operation of the first type may be understood readily by reference to Figs. 399 and 400. In Fig. 399 the diaphragm is attracted directly by the electromagnet, while in Fig. 400 the diaphragm, or sound-producing element, is vibrated by a plunger attached to an iron armature, which in turn is actuated by the magnetic action of the electromagnet.

In the mechanically-operated type the diaphragm, or sound-producing element, is operated by a ratchet wheel which may be made to revolve either by hand or by an electric motor, depending upon its construction. The fundamental principle of the mechanically-operated horn is shown in Fig. 401. A glass-hard tooth wheel W is made to revolve and causes the button B, which is attached to the diaphragm, to vibrate. This toothed wheel may be in a horizontal position or parallel to the diaphragm as shown in Fig. 402, which shows a cross-section of an electric motor used in revolving the wheel. The tooth wheel is carried on the same shaft as the armature M, and the end thrust is taken care of by an end thrust bearing at the left hand end. The adjustment of the horn is made by turning the screw S until the desired note is obtained when the horn is run-



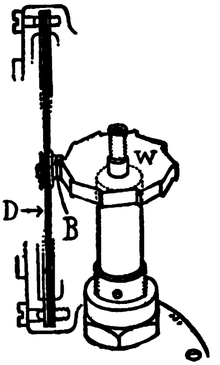


Fig. 401—Right—Construction of mechanically-operated horn
Fig. 402—Left—Electric motor operated horn

ning and then locking S in position by the nut A. The working parts are all inclosed by the cover C.

The interior views of two different types of hand operated horns are shown in Figs. 403 and 404. The toothed wheel in the horn shown in Fig. 403 is driven by a spiral plunger which must be depressed by hand. Adjustment of tone in this case is provided by varying the pressure in a spring in front of the diaphragm which passes the diaphragm against the toothed wheel.

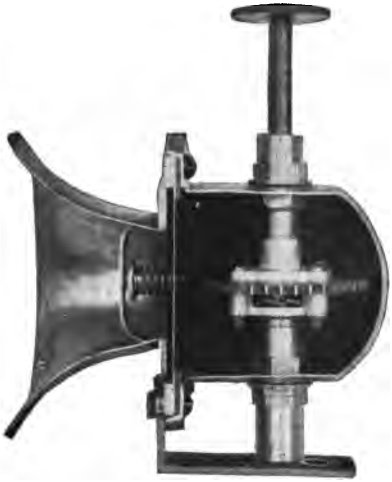


Fig. 403—Cross section of typical hand-operated horn

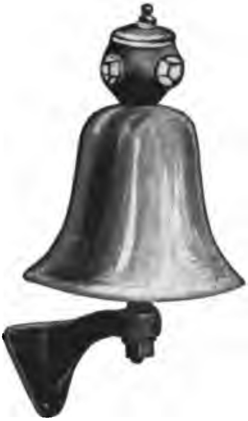


Fig. 405—Electrically-operated lamp-bell

The toothed wheel in the horn shown in Fig. 404 is driven by a special bevel gear. The larger member of this gear is rotated by turning a handle on the back of the horn. The handle may be rotated in either direction.

An unusual form of electric signal is shown in Fig. 405, which consists of an electrically-operated bell. The bell itself is cast from bronze and on top of it is mounted a smaller compartment containing a small electric lamp and provided with windows of polished ruby jewels. Inside the bell is an electromagnet which operates the clapper through special alloy contacts. The bell is provided with a bracket for fastening it to the front of the radiator.

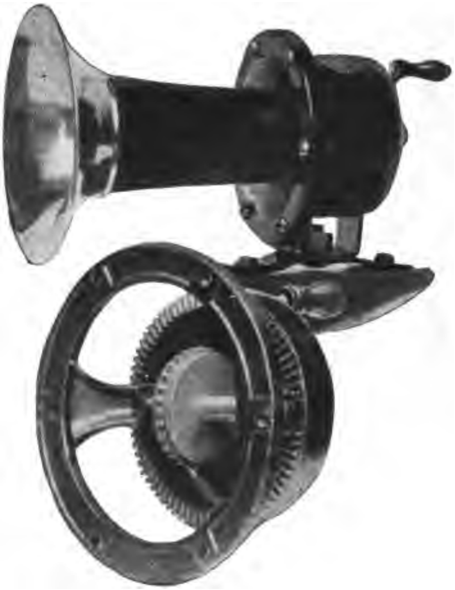


Fig. 404—Exterior and interior of crank-operated horn

Care of Electric Horns

The care of the buzzer type of electric horn is practically the same as that given the electric cut-out and the regulators used with the generators. It will be necessary to clean and true up the contact points at intervals and it more than likely will be necessary to adjust the spring. A weak sound may be due to a discharged battery, open circuit, grounded circuit or lack of adjustment. An open circuit may be caused by a broken wire, poor contact in push buttons, loose connection or lack of adjustment in horn, which may result in the contacts not making contact and no current can pass through the winding of the electromagnet.

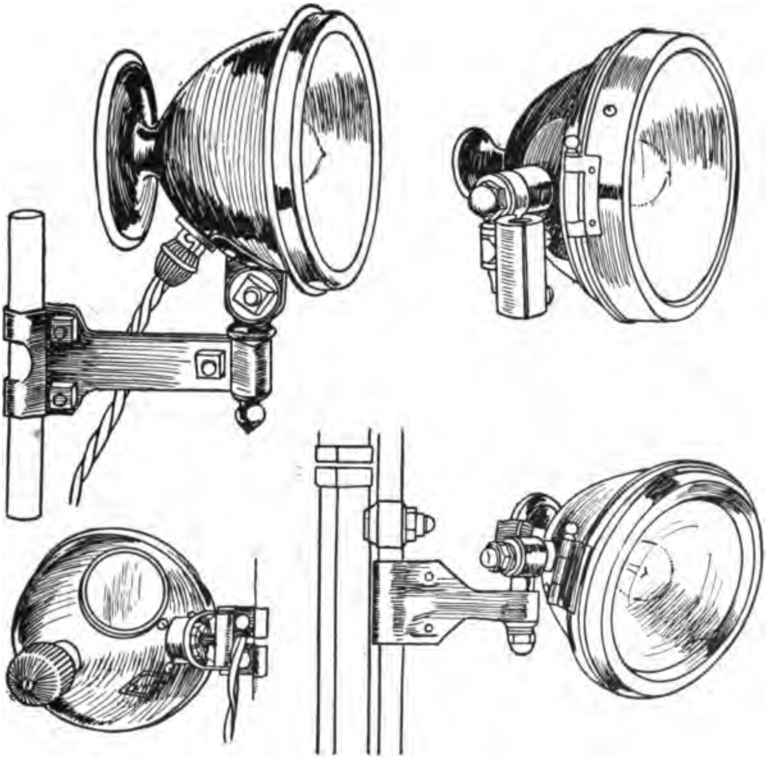


Fig. 406—Several forms of spotlights and mountings

In the motor-driven type of horn the commutator and brushes will require attention at more or less regular intervals, depending upon the use that is made of the horn. A horn of this type may fail to operate due to a broken wire, grounded circuit, loose connection, dirty commutator, brushes not properly adjusted, poor contact in contact button, or the battery may be exhausted. It may happen that the motor will run but the horn may produce a very weak sound or no sound at all and in such a case it is due to the poor contact between the toothed wheel and the button on the diaphragm. An adjustment may remedy this difficulty or it may be necessary to replace either the button or toothed wheel or both as they will wear out in time in spite of the fact that they are both made glass hard.

Spot Lights

The primary purpose of a spotlight is to afford a light which may be directed by the driver or other occupant of the car in any direction, independent of the direction in which the car is traveling. The spotlight consists of a parabolic reflector provided with a suitable incandescent lamp mounted in a containing case with a glass front and fastened to an adjustable bracket attached to some part of the car within easy reach of the party who is to control the direction in which the light from the lamp is to be thrown. Very frequently the spotlight housing is provided with a mirror by which the driver may be able to determine what is behind him while driving during the day, provided the spotlight is fixed in a definite position. The switch controlling the spotlight may be mounted in the handle on the housing or it may be placed on the

Fig. 407—*One form of trouble lamp, lower, with light installations* cowl board or within easy reach of the operator. Several different forms of spotlights and brackets are shown in Fig. 406.

Trouble Lamps

The trouble lamp usually consists of a small reflector on the end of a convenient handle and provided with an incandescent lamp of proper voltage. A flexible extension cord is provided for connecting the lamp to one of the lamp sockets on the car or one specially provided for the trouble lamp. One form of trouble lamp is shown in Fig. 407. In some forms a reel is provided upon which the extension cord may be wound. The reel usually is operated by a coiled spring which is under tension when the extension cord is pulled out.

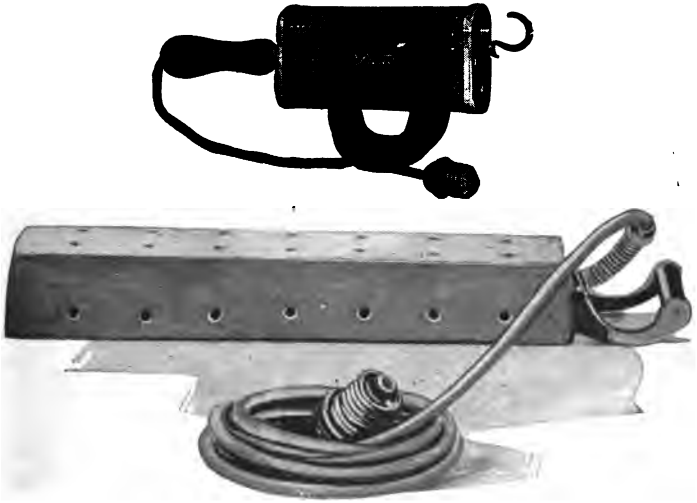


Fig. 408—*Two kinds of electric heating devices*

Electric Heaters

The electric heater is a device in which electrical energy is converted into heat energy. A device of this kind frequently is used in keeping the engine warm and preventing the radiator from freezing in a cold garage. Two electric heaters for this purpose are shown in Fig. 408. The electric heater is sometimes installed in the intake manifold to get better carburetion and thus facilitate starting. A device of this kind is shown in Fig. 409.

Signals and Direction Indicators

Several different kinds of electric signals and direction indicators have been devised and perfected so that the driver of a car may give notice to those immediately behind of his intention to stop or turn to the right or left with a view to eliminating the danger of collision. Devices of this kind are shown in Fig. 410. The Warner device shown at A in the figure consists of a brass outer housing with a rectangular opening cut out in the back side of it. Inside this brass shell there is a glass tube directed into four sections. On one of these sections there appears in large letters the word STOP. Another section is colored plain red and the other two are labeled TURN with arrows pointing to the right and left respectively. Three electromagnets are mounted inside the brass shell at one end, and these magnets may be made to act upon an armature attached to the shaft upon which the glass tube is mounted. The position of the glass tube, of course, will depend upon which of the magnets is acting upon the armature, which in turn will depend upon which button or circuit is closed. In the cross-section shown, the armature is at the bottom where it

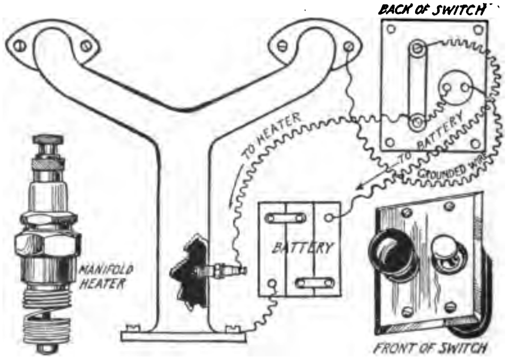


Fig. 409—Manifold heating device, left, showing installation

tends to stay normally under the action of gravity, the magnets being de-energized.

The Safety-Lite signal which is shown at B in Fig. 410, indicates the direction in which a car is going to turn by means of arrows. The device consists of a metal containing case containing electric bulbs which may be controlled from the dash or steering wheel. The light from the electric bulbs, depending upon which one is lighted, brightens either the right or left arrow so as to render it clearly visible to a driver in the rear.

A third form of signal, called the Pomeroy, is shown at C in Fig. 410. This signal is provided with three solenoids. Two operate the swinging indicator lever so as to show L or R, and the third controls a shutter which normally hides the word stop from view.

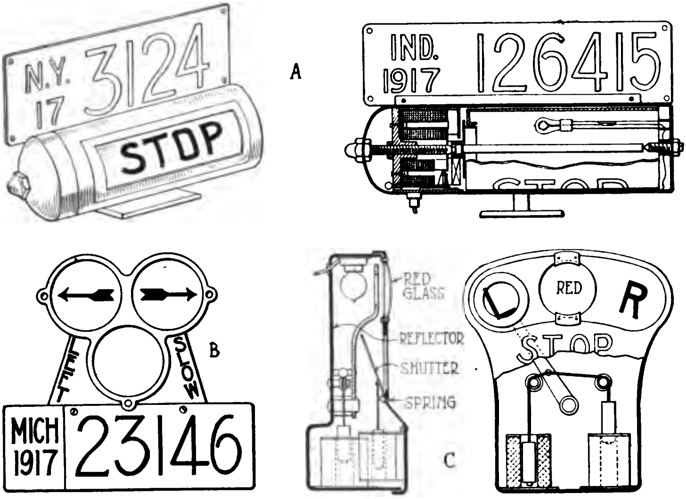


Fig. 410—*Several different types of signals*

There are many other forms of signals and direction indicators, but they all have a common purpose, and their operation should be made as near automatic as possible. For this reason in a great many cases, the electrical circuits controlling their operation are opened and closed by the driver in operating some part of the car, such as pressing the brake pedal, which will cause the word "stop" to appear on the signal board.

The Electric Brake

The object of the electric brake is to provide an easily operated electrical means of applying the brakes on a car and thus do away with the manual labor usually connected with their operation. In the Hartford electric brake a high speed series motor is used, and this motor may be wound so that it may be operated from any voltage source of electric energy available. For motor car work the more common voltages are 6, 12 and 24 volts. The armature shaft of the motor carries a worm which engages a worm gear, the reduction being 100 to 1. This worm gear drives a drum through the medium of an internal gear at a reduction of 4 to 1, which makes the total reduction from motor shaft to drum 400 to 1. The pull of the motor is transmitted to the brake mechanism by a steel cable one end of

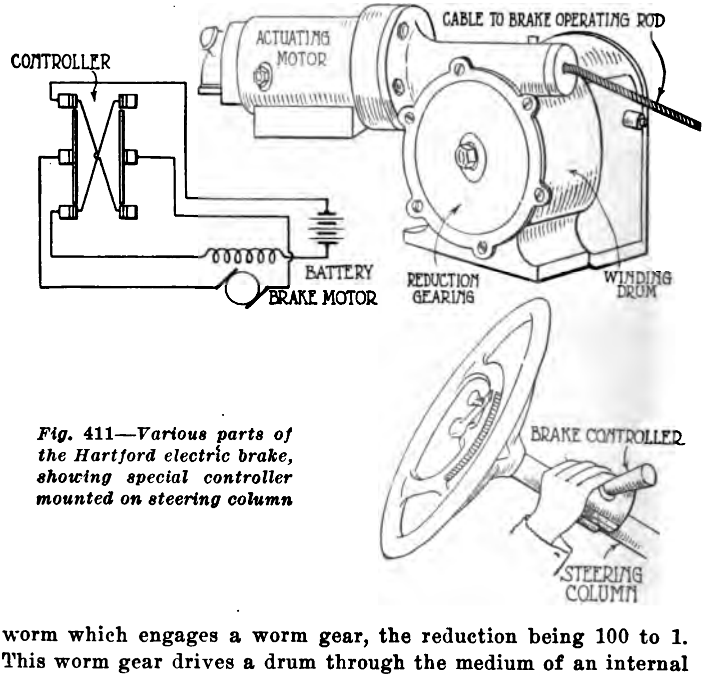


Fig. 411—Various parts of the Hartford electric brake, showing special controller mounted on steering column

which is attached to the brake equalizer and the other end winds on the drum.

The motor is controlled by a special controller mounted within easy reach of the driver as shown in Fig. 411. The first point on this switch, which is a two-point affair, gives ample braking power for all ordinary requirements, while the second point gives a much greater braking power and is used in making emergency stops. Restoring the switch to its original position immediately disengages the brake.

The motor used in operating the brake is capable of making 10,000 revolutions per minute when running idle, and under load it can exert a pull of 1000 pounds at a speed equivalent to a quick application of the hand emergency brake. A slipping clutch prevents the motor from exerting a pull in excess of 1000 pounds, and a ratchet prevents the brake from slipping off. The powerful pull excited by the motor on the brake cable permits of operating the emergency brake in oil. The motor will take a current of 40 amperes for approximately two-fifths of a second from a 6-volt battery for each application of the emergency brake.

Electric Vulcanizers

The electric vulcanizer is a vulcanizer in which the heat is supplied by passing an electric current through a resistance unit. This resistance unit is mounted in half of the vulcanizer or in one of the plates. Thermostats are provided in some for automatically cutting off the current when the temperature has attained the correct value, and others have a thermometer opening or pocket into which a thermometer may be placed and the temperature observed. These vulcanizers are provided with flexible leads and are wound for different voltages ranging in value from 6 to 110 and 220.

CHAPTER XXVII

Electric Gearshifts and Transmissions

THE electric gearshift is another valuable addition to the electrical equipment of the motor car which has been made possible by the installation of a charging generator and a constantly changed storage battery.

Four movements are necessary to engage all of the speeds in a standard three-speed forward and out speed, reverse gear of the selective type. These various changes are carried out as follows: A sliding pinion is used for first and second speeds, a toothed clutch for the direct drive and an idler between two of the gears for giving the reverse speed. All of the preceding movements are accomplished by a yoke attached to the member being moved. The yoke is attached to a movable bar, which is in turn connected to the hand lever through a convenient linkage. The electrically-operated gear is identical to the arc described and all the parts mentioned are retailed with the exception of the hand lever. The two movable bars to which the yokes are attached are lengthened somewhat, and their ends form armatures or cores for four solenoids.

The principle of operation of the electric gearshift may be understood easily by reference to Fig. 412, which shows in a simplified diagrammatic form the operating electrical circuit, push buttons and solenoids. There are four solenoids, one for each movement necessary. If you press button 1 you close the circuit solenoid 1, causing the movable bar A to move to the left. If you press button 2 you close the circuit to solenoid 2, causing the movable bar A to move to the right. If you press button 3, solenoid 3 is energized and the movable bar B moves toward the left, while if you press button R solenoid R is energized and the movable bar moves toward the right. Pressing the button N, called the neutral button, and then throwing out the clutch neutralizes the gears, that is, all gears are disengaged and the engine is no longer connected to the propeller shaft.

The above buttons, which are mounted within easy reach of the driver, usually upon the steering post, when pressed do not entirely close the circuit to the respective solenoids but merely place the particular solenoid which they control in connection with what is called the master switch. These buttons themselves are referred to as selector switches, because they select in advance the circuit and hence the solenoid which will be energized when the master switch is closed. The master switch is controlled by the clutch pedal, and it is closed when the clutch pedal is pushed down to the extreme position. The clutch pedal has ample movement so that the clutch may be disengaged without closing the master switch.

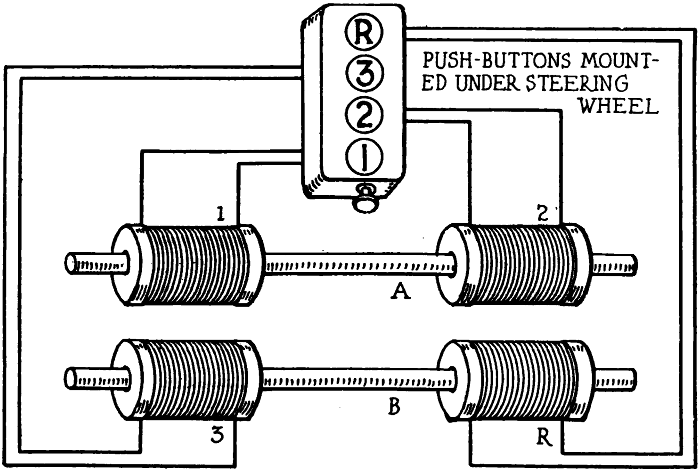


Fig. 412—*Principle of operation of electric gearshift in simplified form*

In stopping the car the neutral button is pressed and the clutch pedal pressed all the way down. When the neutral button is pressed, all the contacts which may have been closed previously by the selector switch buttons are broken, and depressing the clutch pedal then brings into action what is called the neutralizing device. For example, if the car has been running on high and you desire to stop, the neutral button is pressed and the clutch pedal pushed all the way down against the floor board. This causes the lever K, see Fig. 413, to move forward and then the

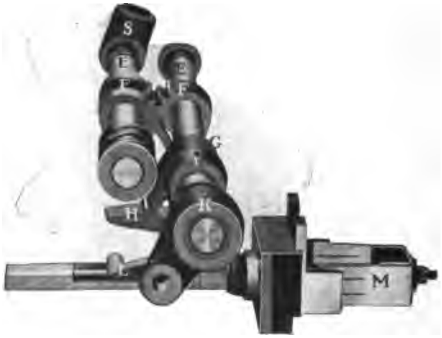


Fig. 413—*End view of Cutler-Hammer neutralizing device and master switch*

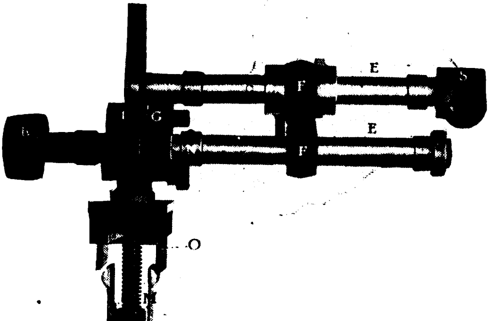


Fig. 414—*Plan view of Cutler-Hammer neutralizing device and master switch* neutralizing causes F to pull on the boss on the shifting forks as if a shift in gears were to be made, and the master switch M will also close. Since the neutral button has opened all of the selector switches, all the solenoids have no current in their winding and the gears remain in neutral. A plain view of the neutralizing device and master switch are shown in Fig. 414, and two of the solenoids with their mountings, are shown in Fig. 415. The relative location of the different parts of the complete device are shown in the phantom view in Fig. 416. The solenoids are marked B 1, B 2, B 3 and B 4 and their respective cores are marked C 1, C 2, C 3 and C 4.

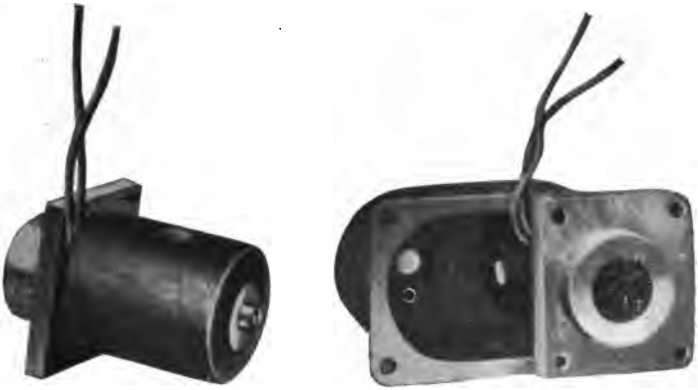


Fig. 415—Cutler-Hammer solenoids and container for electric gearshift

In passing from one speed to another the operation is as follows: The selector switch corresponding to the desired speed is pressed and the clutch pedal is rotated all the way forward, which rotates the operating lever K and its shaft upon which the rocker arm I and its mechanism are mounted. The latch H is in engagement with the pawl G of the neutralizing mechanism, and as the operating lever and the rocker arm I are rotated, the latch H presses against the pawl G, causing both of the neutralizing cams F to rotate toward the center as they are engaged through the teeth P. On the central side of the shifting fork D, Fig. 416, is a boss and as the neutralizing cams rotate they press against the boss on whichever side is in engagement, and the shifting fork and the gear with which it is engaged are pulled back to the neutral position before the next shift can be made. As the gear comes into the neutral position, the end of the latch H strikes what is called the knockout pin, which action releases the latch from engagement with the pawl G, and as the operating lever K is moved ahead by the lever pressing down on the clutch pedal, the switch operating pawl L pulls against the switch stem and closes the circuit at the master switch. The gears may be changed by hand, should the battery become exhausted, by inserting an emergency hand lever in the socket S and the gears changed in the usual manner.

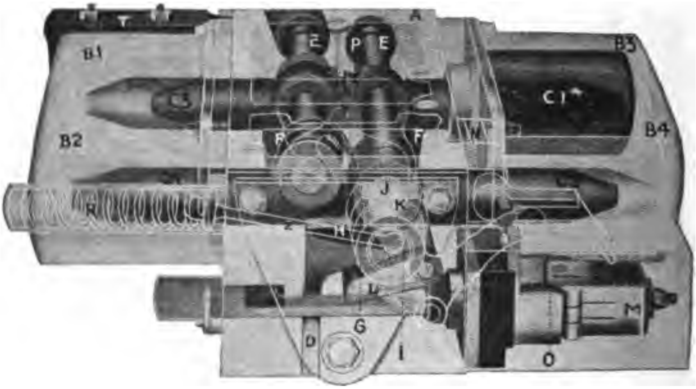


Fig. 416—Phantom view of Cutler-Hammer electric gearshift

In starting, all gears are in neutral. The first thing to do is to press the first-speed selector switch which connects one of the solenoids to the master switch. Next depressing the clutch pedal all the way down rotates the lever K, see Fig. 413, through the connecting rod L which is attached to the clutch pedal. This operation pulls the blades of the master switch M into contact which completes the circuit and energizes the first speed solenoid. As the gears are engaging and while the sliding member is within about ½ inch of being at the end of its movement, the pawl G, see Fig. 414, falls back due to the pull of the magnet against the trigger N, which is attached to the switch operating pawl

L. The pawl L, due to this action, is made to raise out of engagement with the stem of the master switch and the switch opens instantly due to the action of the spring O. The time of this operation during which current is drawn from the battery is in the neighborhood of one-third of a second.

Wiring of Gearshift

A complete wiring diagram of the electric gearshift is shown in Fig. 417. A single wire leads from each solenoid through the terminal block to its particular button, while the other terminal of all the coils is connected to a common terminal thence to the master switch and battery. The remaining terminal of the battery is connected to a common bus beneath the selector switches. The connectors at the terminal block are considerably simplified by making each terminal a different size so that the wires can be replaced only on the terminals where they belong.

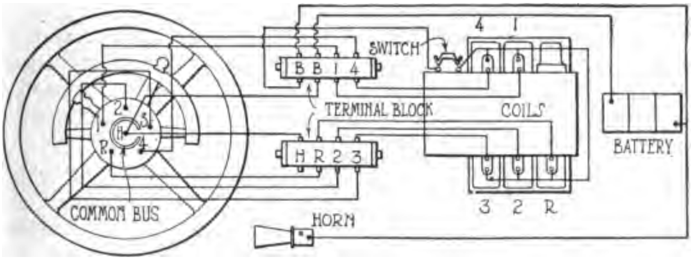


Fig. 417—Complete wiring diagram of electric gearshift

The following are some of the most likely causes of trouble in the operation of the electric gearshift:

First, exhausted or too weak a storage battery.

Second, a break in the link connecting L to the clutch pedal.

Third, dirt in the master switch contacts of wear of same, thus preventing contact.

Fourth, failure of the spring O, which closes the master switch.

Fifth, loose connections due to vibration at the terminal block or selector switches.

Sixth, jamming of solenoid cores in the brass tubes due to the shaft getting out of alignment. This may be tested by using the emergency hand lever to see if the gears shift easily.

Seventh, broken connections in the wires or windings, which are not very likely to occur on account of the excellent protection.

Woods Dual Power Car

Motor cars propelled by a combination gasoline and electric powerplant are called dual power cars. The possibilities in the arrangement of the control of a car of this kind are very great, yet the control must be as simple as the ordinary gasoline car and at the same time allow the driver to use both the engine and the electric powerplant to the best advantage under all conditions of driving. Some of the advantages of the dual power system will be apparent after reading the description of the operation of the engine and motor combination. One of the best examples of a car of this type is found on the Woods dual power car, manufactured by the Woods Motor Co., Chicago.

The powerplant of the Woods dual power car, a plan view of which is shown in Fig. 418, consists of a four-cylinder Continental 2¾ in. gasoline engine, a magnetic clutch of Cutler-Hammer make, a compound-wound dynamotor manufactured by the General Electric Co. and rated at 48 volts and 60 amperes and a special Exide storage battery of 24 cells having a capacity of 115 ampere-hours based on a 5-hour discharge rate.

The engine, clutch and dynamotor are combined into a single unit from which the power is transmitted direct to the rear axle without passing through a variable gear. A Baush undermounted worm gear is used in the rear axle, having a reduction of 8.25 to 1.

The magnetic clutch is of the plate variety and is combined with the flywheel. A coil is set into a recess cut in the flywheel rim, and when this coil is undersized the clutch plate is drawn against the flywheel rim by the magnetic force produced by the current. The clutch plate is faced with asbestos fabric, and the clutch cannot be seriously injured by slipping.

The dynamotor is of the compound-wound type and its motor characteristics are somewhat different from the characteristics of the motors found in the ordinary electric vehicle or when the car is being driven by the gasoline engine alone, when the clutch current is taken direct from the armature of the dynamotor. The

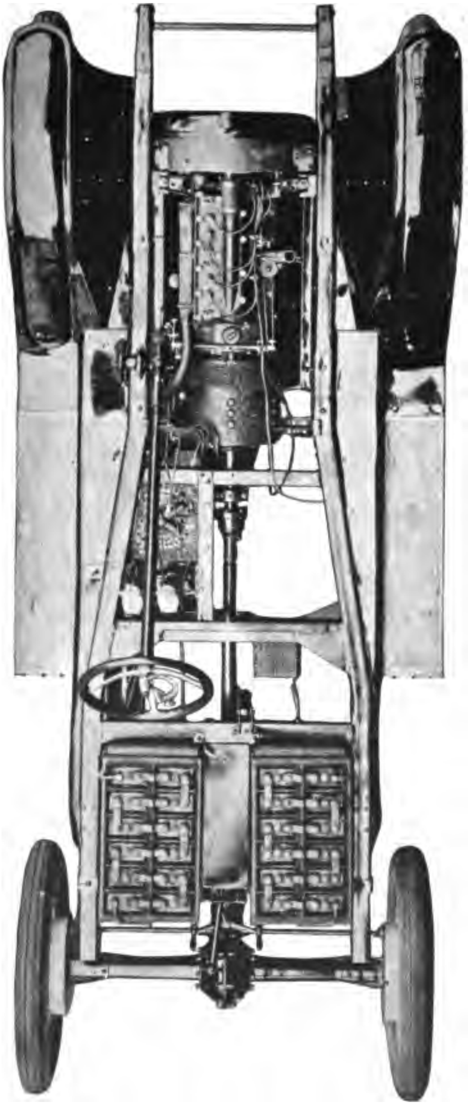


Fig. 418—Plan view of powerplant of Woods' Dual Power motor car which is a combination gasoline and electric

dynamotor is used in starting the car just as an ordinary clutch is started, when the engine is at rest.

The starting controller, or the control panel as it is called, and the reversing switch are located under the driver's seat and there is a shunt field control rheostat under this foot board. There are two finger levers on the steering wheel. The outer of these two levers controls the field rheostat, and when this lever is at the top of the wheel, all the field resistance is in circuit. The inner finger lever controls the clutch circuit and the throttle. When the car is standing and the engine is idle, both finger levers are near the bottom of the sector on the steering wheel, and moving these levers forward or up has the effect, while the car is in operation, of increasing the speed, and in this respect the control is similar to the gasoline car. The first slight movement of the inner finger lever opens the throttle of the gasoline engine, and continued movement of this same lever closes the circuit of the magnetic clutch, which operates on full battery voltage, except when the car is being reversed, when the clutch is free or when the car is being driven by the gasoline engine alone, when the clutch current is taken direct from the armature of the dynamotor. The throttle continues to open as the lever is moved upward until the top-notch position of the lever is reached.

The main switch on the control panel, which connects the dynamotor to the battery, is not operated directly or mechanically by the driver but through the medium of a solenoid.

In addition to the main switch for connecting the dynamotor to the battery, there is a secondary switch located under the main switch. The purpose of this secondary switch is to short-circuit the starting resistance when the current drawn from the battery by the dynamotor, which is operating as a motor, has dropped down to about 175 amperes. This operation of the secondary switch is accomplished by a differential electromagnet. The switch is held open by a series winding through which the main current of the dynamotor passes and is closed by a shunt winding. At the moment of starting from rest, the motor draws a very heavy current from the storage battery, which may amount to as much as 400 amperes. This very large current makes the series winding very powerful and the secondary switch is held in the open position, although the shunt winding tends to close it. As the current taken by the motor decreases in value the magnetic action of the shunt winding finally overpowers the series winding and the secondary switch closes, cutting out the starting resistance.

Adjacent to the main and secondary switches is a reversing switch by which the armature leads of the dynamotor are reversed to permit backing the car by electric power only. There is an interlocking mechanism between the right-hand control pedal and the reverse switch, so arranged that the reversing switch cannot be operated unless the right-hand control pedal is pressed forward until the brake is applied. A complete wiring diagram of the car showing all constructions is given in Fig. 419.

In starting the car the operations are as follows: First the lock switch on the steering wheel is turned to the "on" position, which closes the main switch operating solenoid at this point and the ignition circuit also is closed. Next the outer finger lever is moved a short distance up on the sector, which closes the circuit of the main switch solenoid at another point. The circuit of the main switch solenoid is now complete and the main switch closes, causing the car to start forward as an ordinary electric. To start the engine the inner finger lever is moved up on the sector a short distance. The first motion of this lever opens the throttle slightly and further movement closes the magnetic clutch circuit and opens the throttle more. As the throttle is opened up still more the engine speeds up or tends to do so and thus assists the electric motor in propelling the car. If the field resistance of the motor remains fixed in value and the power supplied by the engine is increased by opening the throttle, then the speed of the car will be increased slightly and the engine will supply a larger and larger part of the total power supplied to the propeller shaft until the motor is delivering no power at all, as the voltage generated in its armature at this higher speed is then equal and opposite to the voltage of the battery. A further increase in speed changes the motor to a generator and it starts to charge the battery. The speed at which the machine changes from a generator to a motor or from a motor to a generator will depend upon the value of the resistance in the field circuit, provided the battery voltage is constant. The lower this resistance the lower the speed at which this change takes place. Weakening the field of the dynamotor lowers its voltage and decreases its generator action if it is acting as a generator or tends to

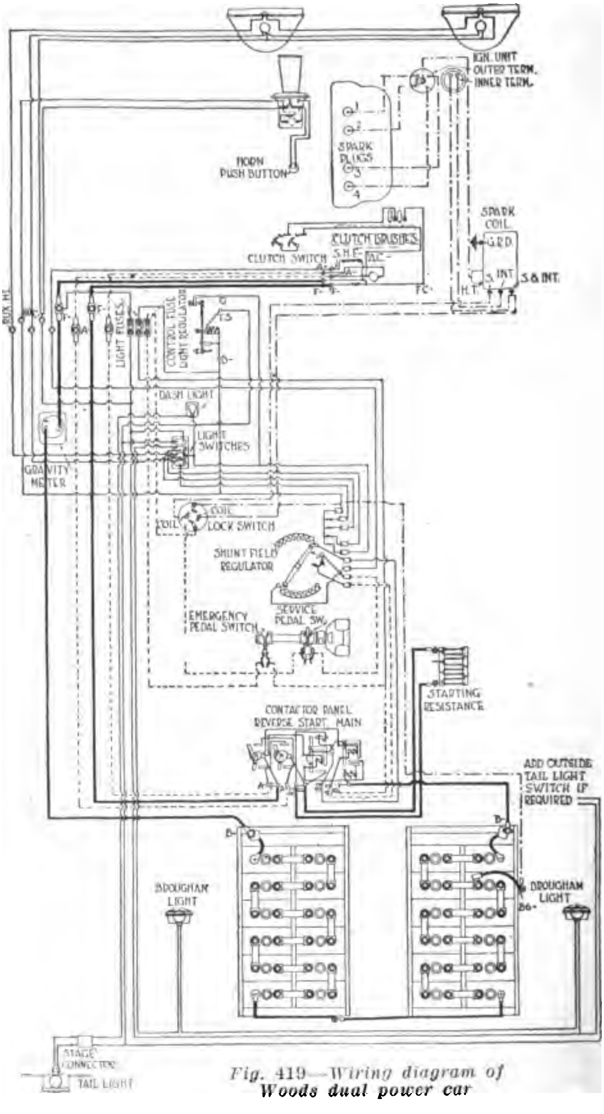


Fig. 419—Wiring diagram of ***Woods dual power car***

increase the speed if it is acting as a motor. It is possible to run the car on the gasoline engine alone with the dynamotor entirely disconnected from the battery.

Magnetic Braking

If the voltage in the armature of the dynamotor is greater than the voltage of the battery, a charging current will be sent through the battery and the dynamotor acts as a generator. Power, of course, is required to drive the armature of the dynamotor when it is delivering power to the battery and this power, as in the case of dynamic braking, may be derived from the rear axle due to the tendency of the car to run down hill or coast. This braking effect can be increased by cutting out resistance in the field circuit. This results in the energy stored in the car being transformed into electrical energy in the battery instead of being wasted in heating and wearing the brake bands.

Entz Transmission

The principle of operation of the Entz transmission is really that of the clutch. The Entz transmission is an electro-magnetic clutch which is always slipping, sometimes a great deal, sometimes a very little; and the energy dissipated by the slip is recovered to be used again later on. If a car had a clutch made of some material which could not be burnt or worn out, it would be possible to arrange a transmisison by a purely mechanical device for tightening or loosening the grip of the clutch, but if this were done, the instant the clutch began to slip energy would be wasted in the form of heat. This heat energy could not be recovered, and also the more we wanted to use the slip so as to give the effect of a lowered gear ration, the greater the proportion of the energy that would be wasted.

The Entz magnetic transmission is a clutch that can be tightened magnetically, but the slip creates electrical energy instead of heat energy, and this electrical energy is used to drive the car. The power of the engine is delivered at high speed, and relatively low torque, and transformed into power at low speed and high torque at the rear axle without any direct mechanical connection through gears or a slipping mechanical clutch of any kind.

The two essential elements of the electrical transmission are units of electrical machinery that central station work or nearly

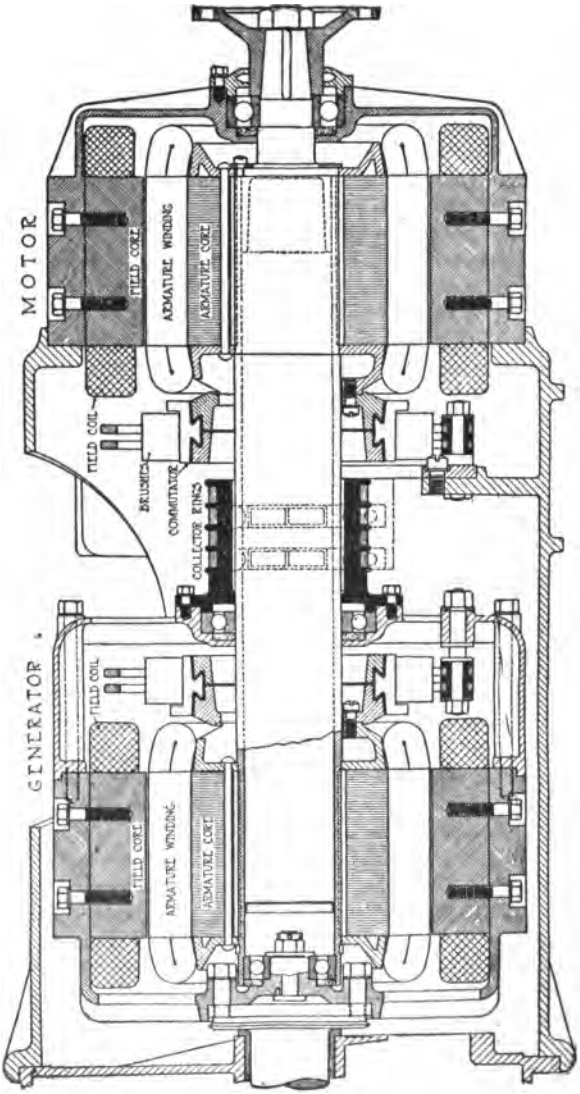


Fig. 420—Cross-section of the complete Entz magnetic transmission

two generations has proved good and reliable. Added to this is the extremely important point that the brushes and commutator bars which are the only parts of an electric generator that are at all likely to wear out are hardly ever used anything like so hard as they would in lighting service. Like all other transmissions, the Entz transmission does most of the work on high gear, and the difference in the speed between the electrical moving parts is then only from 60 to 100 r. p. m., as compared to several hundreds of revolutions for a central station dynamo or several thousand for motor car lighting generator. It is thus obvious that so slow a rubbing speed of brushes on the commutator as this can produce but very little wear, and the life of the parts ought to be very good.

General Arrangement of Parts

Turning to Fig. 420, which is a cross-section of the complete transmission, it is seen that the field magnets and coils of the generator form the flywheel of the engine. Neglecting the motor part of the transmission, the armature of the generator is on a shaft running free from a spigot ball-bearing in the flywheel and attached at the other end to the driveshaft and so to the level pinion of the rear axle. Thus the field of the generator runs always at propeller shaft speed.

The effect of running the engine and so spinning the field magnets of the generator is to reduce currents in the armature which make a magnetic attraction between the armature and the field. This is equivalent to tightening the fields upon the armature if we follow the clutch analogy, so the armature tries to turn with the field and will do so if the resistance to motion of the car as a whole is not too great. This means that part of the energy delivered by the engine is used in developing electrical energy in the armature and part to the direct mechanical work of turning the propeller shaft and so driving the car. Now this electrical energy which is developed in the armature of the generator is taken to the second part of the transmission, which is an electric motor. This is also shown in Fig. 420, and its field magnets are fixed stationary, while the armature is keyed to the same shaft as the armature of the generator. Thus, whatever else happens the two armatures are always running at the same speeds, and that speed is the speed of the propeller shaft.

Various Positions of Controller

On the foot, or lower, end of the steering column is an aluminum core containing sundry resistance coils and several switches. The effect of moving the controller lever on the steering wheel is described in electrical terms, and the description should be read with continuous reference to Fig. 420, as well as the various circuit diagrams given for each position of the controller, remembering all the while that:

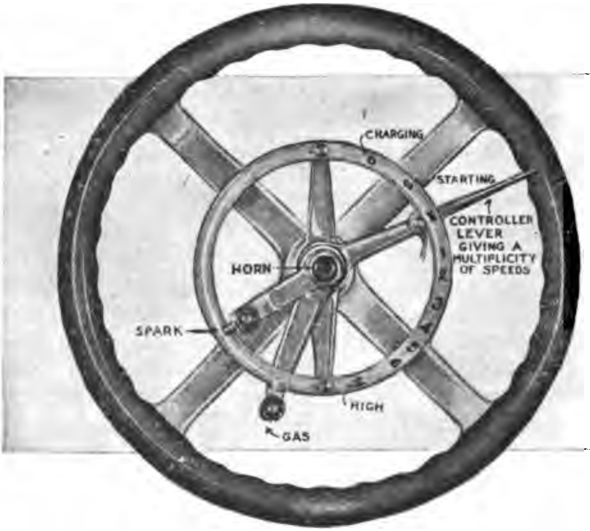


Fig. 421—Controller lever on steering wheel for Entz magnetic transmission

(a) The generator field runs at engine speed.

(b) The motor field is stationary.

(c) Both armatures move together at propeller shaft speed.

Neutral Position—All circuits are open and no electrical energy is being generated or used. The battery is idle unless in use on the lamp circuit at night. A diagram of the connections for this position is given in Fig. 422.

Cranking Position—Current from the battery is switched into

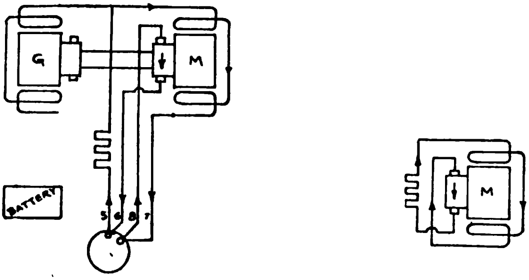


Fig. 422—*Connections for neutral position of controller and electric brake*

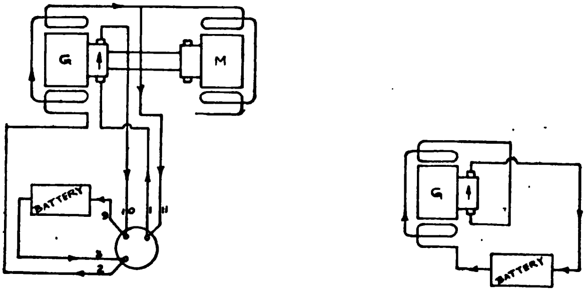


Fig. 423—*Connections for cranking position of controller*

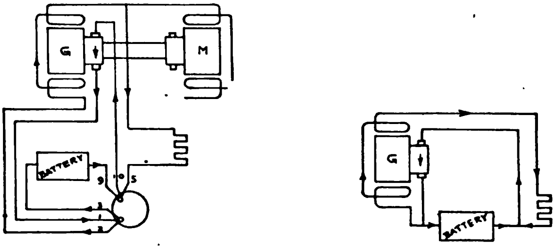


Fig. 424—*Connections for charging position of controller*

the generator, causing it to behave as a motor and spin the engine. The connections are shown in Fig. 423.

Charging Position—When the control lever is in the charging position, the battery may be given a much higher rate of charge than would be safe to establish for running conditions. So that if, for any reason, the battery should be run down, it can be brought up in a short time, as a high rate of charge is permissible for a battery that has not reached the gas point and is not warm. The connections for this position of the controller are shown in Fig. 424.

First Speed Position—Generator is producing light clutching effect and supplying maximum current to the motor. There is a maximum difference between engine and propeller shaft speeds, and greatest torque or pulling power is being developed. Connections are shown in Fig. 425. The generator field is shunted so as to weaken it, while the motor field is full strength, being unshunted.

Second Position—Clutching effect of the generator is increased and the current supplied to the motor is decreased, which results in the car speeding up. The connections are shown in Fig. 426. Both the fields are unshunted, but the motor field is still the stronger, due to its being wound with more turns.

Third Position—Clutching effect of the generator is increased further and transmits more of the driving power direct to the propeller shaft. The motor does the work and the car increases in speed. The connections are shown in Fig. 427. The generator field is unshunted, but the motor field is shunted, and it is weakened as compared with the generator field, in which case it gives less torque for a given current but also less counter electromotive force, and therefore less slip at the generator.

Fourth and Fifth Positions—The generator does more work and the motor less at the fourth position than in the third position, and there is a similar change in passing from the fourth to the fifth position. The generator field is unshunted but the motor field is shunted, and the resistance of this shunt is decreased as the controller moves toward a higher position.

High Speed Position—In this position the generator clutching effect has increased to nearly locking point, and all the driving power is being transmitted direct to the propeller shaft. The motor no longer assists the generator but itself acts as a generator to charge starting and lighting. The connections are shown in Fig. 428. It will be noticed that the motor has a shunt field in this position of the controller, which is opposed by a series field in the battery circuit, making it a differential generator with an inherent self-regulating characteristic.

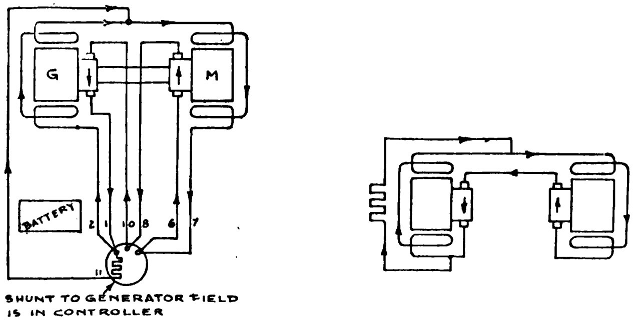


Fig. 425—*Connections for first-speed position of controller*

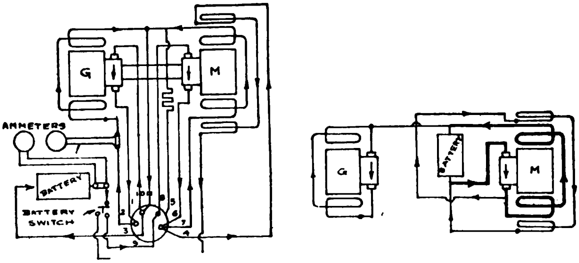


Fig. 426—*Connections for second-speed position of controller*

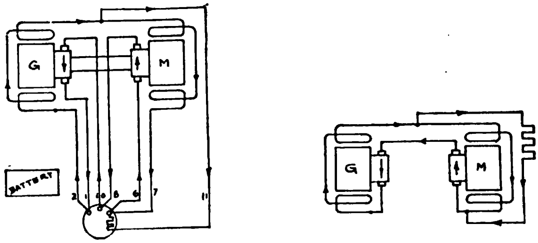


Fig. 427—*Connections for third-speed position of controller*

Electric Braking

An additional feature of the transmission is to provide an extremely powerful electric brake which automatically releases as the car slows down. It cannot be used for stopping the car altogether, because its breaking power depends upon the motion of the vehicle, but it is very effective when the car is traveling fast. If the controller lever be put into the neutral position when the car is running, the heavy current induced by the motion of the car in the circuit shown at the right in Fig. 422 causes a heavy retarding action to the progress of the car. On grades this electric brake will keep the speed down to 15 or 20 m.p.h.

Merits of Entz Transmission

Some of the merits of this transmission as pointed out by its manufacturers are as follows: In this system there are no automatic cutouts or regulators or roller ratchets. There are no chains or gear drives for any of the parts. There are two ample sized dynamo machines, direct connected, and a drum controller. These take the place of separate starting and lighting systems with their complicated means of driving and regulation, of the friction clutch and its actuating mechanism, and the gearshifting transmission, as well as such telescopic and universal joints and numerous grease cups that attend them. The car can be brought up to speed without a jar or jerk. All power impulses of gasoline engine are practically eliminated, and the torque delivered by the propeller shaft to the rear axle is very uniform. The speed of the car is easily managed in traffic and on grades without the necessity of shifting gears.

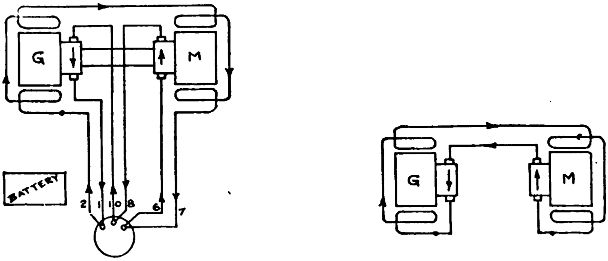


Fig. 428—Connections for sixth-speed position of controller

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